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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN 371.

DRAINAGE OF IRRIGATED LANDS.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., May 10, 1909.

SIR: I have the honor to transmit herewith a report prepared by Charles F. Brown, Drainage Engineer, under the direction of C. G. Elliott, Chief of Drainage Investigations of this Office, upon the drainage of irrigated lands which have been seriously injured or rendered wholly unproductive by the seepage of irrigation water or by the rise of alkali, or by both combined.

While the report gives the details of experiments in the State of Utah only, the localities are so widely separated and cover such a variety of soils and conditions that the lands are fairly representative of irrigated lands elsewhere which require drainage. The work was conducted by Drainage Investigations of this Office in cooperation with the Utah Agricultural Experiment Station.

It is estimated that not less than 150,000 acres of irrigated land in Utah have been ruined or seriously injured by seepage or alkali, and will require drainage in order to restore them to a productive state. In all other irrigated States from 10 to 20 per cent of the land which has been under irrigation for ten years or more requires drainage. This report not only describes the condition of the land, the details of its draining, and the results which were obtained in particular cases, but gives carefully drawn deductions from the experiments, together with directions for draining lands which have become too wet or too alkaline under the ordinary methods of irrigation for profitable cultivation. Methods of draining are not so well established for irrigated land as for land in humid areas, which fact suggests the propriety of describing methods that have been tested in specific cases.

Since the matter contained in this report relates to farm drainage in the arid States, and thus supplements Farmers' Bulletin 187, Drainage of Farm Lands, I recommend its publication as a Farmers' Bulletin.

Respectfully,

A. C. TRUE,
Director.

HON. JAMES WILSON,
Secretary of Agriculture.

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DRAINAGE OF IRRIGATED LANDS.

INTRODUCTION.

The general need for drainage of irrigated lands has increased rapidly during the last twenty years. The most productive lands of these regions and those which were first brought under cultivation are, in many instances, now abandoned or fit only for wet pasturage. In Utah alone there are approximately 200,000 acres of irrigated lands needing drainage. Salt Lake Valley has about 34,000 acres of such lands, and several other valleys from 10,000 to 30,000 acres each. There are several localities in which, of the total irrigated lands, 50 per cent are in such condition. California, Colorado, Washington, Montana, and Wyoming are likewise affected, more or less, and in time all of the newly irrigated lands will have their problems of drainage. It naturally devolves upon the holders of such lands to reclaim them. To the end of developing the best methods for accomplishing the reclamation of such lands the Office of Experiment Stations has conducted drainage investigations in Utah, California, Oregon, Washington, Wyoming, Colorado, and Nebraska, with results which justify the conclusion that there is scarcely any land in the irrigated region which formerly produced paying crops, and later became affected by excess of water or alkali, that can not be profitably reclaimed, provided the work is correctly planned and carried out. These results also point to the possibility of reclaiming many virgin lands containing an excess of alkaline salts.

This bulletin, while it applies to all irrigated lands and contains some data obtained in investigations in other States, is based upon experimental work done in Utah. For the localities in which the experiments were performed, see the map of Utah (fig. 1). The drainage investigations of the Office were begun in the State during the summer of 1904 in cooperation with the Utah Agricultural Experiment Station. Since then the work has been carried on with a fund provided jointly by the State legislature and the Office of Experiment Stations, the Utah station acting for the State.^a

^a For further details of the Utah work see Utah Sta. Bul. 99.

DRAINAGE OF IRRIGATED LANDS.

The individual landowners have in every case cooperated with the State and Federal agents in carrying out the work. The attitude of most of them has naturally been one of skepticism as to the success

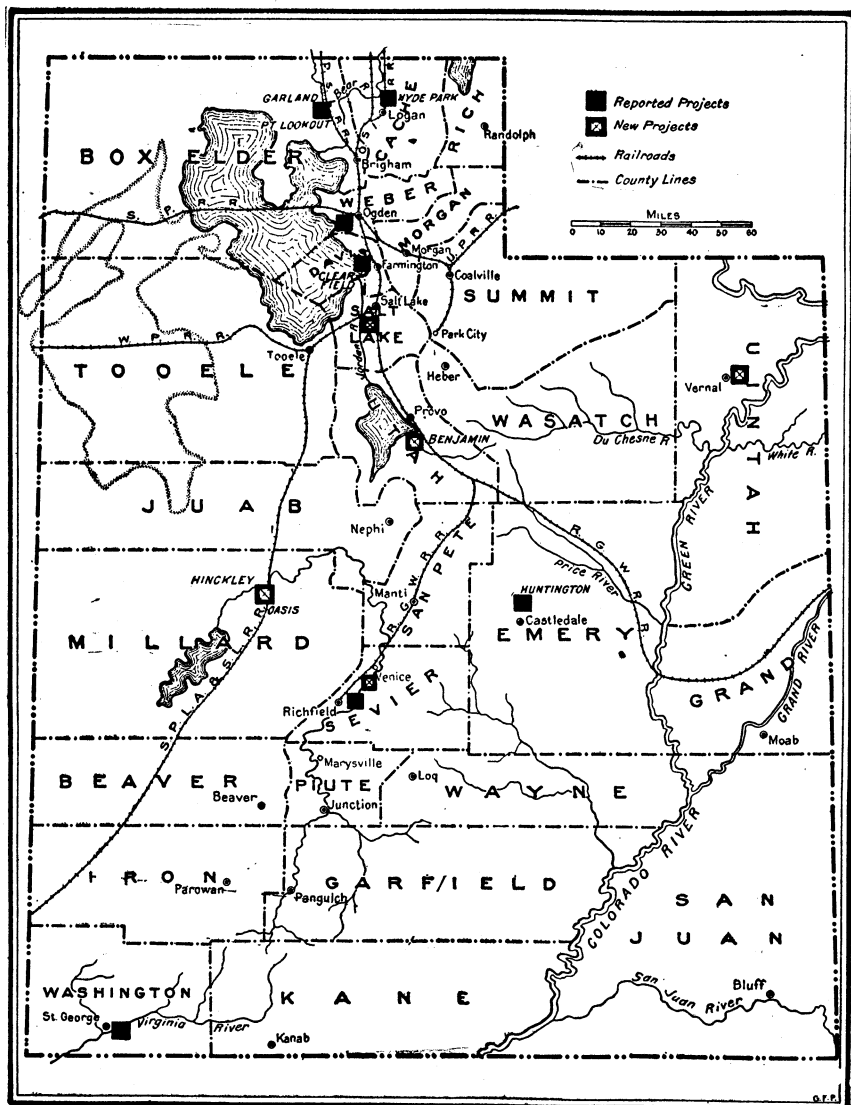


FIG. 1.—Map of Utah, showing locations of drainage experiments.

which could be obtained, and they have been convinced of the feasibility and financial advantage of the methods proposed only by actual successful demonstrations of results on a commercial scale. In one case the county interested also cooperated in the expense.

CACHE COUNTY INVESTIGATIONS.**HYDE PARK EXPERIMENT.**

This experiment was made on lands just south of Hyde Park, in a belt of 2,000 acres, between that town and Logan, which was badly affected by the rise of ground water. The soil is a black loam underlain by yellow clay, both of which are of an open nature and permit the passage of water freely. These lands were among the first brought under cultivation in this neighborhood and originally produced abundant crops. After some twenty years of satisfactory cultivation, a rise of ground water resulted from the irrigation of the higher lands which had in the meantime been brought under cultivation. The amount of seepage gradually increased, and lands which had been tillable for cereals and root crops became unsuited for such crops and were planted to grasses for hay. The tame grasses were driven out in a few years and water grasses of little value prevailed. In the beginning the areas affected were small, but they continued to spread and creep up to higher levels in the typical manner, until few farms were unaffected.

It was noticed that when the fields upon the upper bench, one-half to three-quarters of a mile distant, were irrigated the soil water appeared at the lower levels about thirty-six hours later. This indicated that the primary cause of the wet condition of the lower lands was seepage from the more elevated fields. Observations later established the fact that the water passed through the soil along the line of greatest surface slope until it reached the lower sections, where it accumulated. Owing to the soil structure the ground water passed more readily through some parts than others, thus giving the water an uneven distribution, causing wet spots rather than a uniformly saturated condition of fields, as ordinarily might be expected.

Work was begun at Hyde Park during the summer of 1904.

Plans and Construction.

For the purpose of showing the surface slopes on the following maps (fig. 2 and others) contour lines are employed. Contours are lines running through points of equal elevation, corresponding to successive shore lines which would be formed if a tract could be covered with water and the water level then lowered a foot at a time, allowing sufficient intervals of time between reductions to mark shore lines. These lines are determined by the level and are marked with the elevations relative to a determined datum.

The experimental area is that within the shaded belt. The drains outside this area were laid by the owners in accordance with plans and survey made by the Office of Experiment Stations. The branch

map. These two lines discharged at their junction into an open ditch which gave much trouble on account of the banks caving in. Owing to the obstructions in the ditch the tile lines were kept full of back-water and consequently did not work properly. During the season of 1905 the 10-inch outlet through Hancey's field was laid. An illustration of the rise of water in spots is here shown in the two areas inclosed by dotted lines. The one in the Hancey field remained wet until the 10-inch line was laid through it, in spite of the fact that it was almost surrounded by lines of tile laid the year before. The spot in the Lamb Brothers' field is still wet and needs a branch line cutting through it.

The construction work, except surveying, was done by the farmers. Preparatory to laying out the lines of tile a preliminary level survey was made. This work was simple, consisting of levels at important points, and was made by two men in an hour or two. With the figures thus secured, it was easy to stake the lines with assurance that the depths and grades would be satisfactory. In this and following work two sets of stakes were driven at 50-foot intervals and 6 inches from the edge of the trench. The stake from which the elevations and profile were determined was driven until the top was flush with the surface. The other, a 1-inch by 4-inch by 18-inch stake on which the station number and cut were marked, was set near the grade stake as a guide. Grade was obtained at each station by measurement and between stations by the flow of water. The grade of the bottom made in this way was more or less irregular, but on the whole fairly good, as indicated by the flowing water. The necessity of properly grading the bottoms of the trenches was not appreciated by some of the farmers who put in drains on their own account, and as a result in some cases it was necessary to dig up and relay the tile, because they had become obstructed in low places by sand and sediment. The soil generally was firm and would stand well after trenches were opened, so that the water method of grading, with measurements every 50 feet, was sufficient if followed with care. When the trenches were dug it was noticed that the water entered freely through crevices and channels in streams, some as large as a lead pencil. The subsoil, a granular clay, is somewhat stratified and sufficiently open to admit the moderately free passage of water. On the whole it may be regarded as a soil for which tile or other underdrains are suited, as there is sufficient clay to keep the soil compact. A few sand pockets and other soft spots were encountered in parts of the fields outside of the experimental tract, and boards should have been laid under the tile in these places to insure proper alignment. Neglect to take these precautions resulted in failure in one place. The tile were laid by a man in the trench, and were blinded or carefully

covered with a foot of soil as soon as laid. This is necessary to prevent displacement when filling the trenches by plowing, as is usually done.

Cost.

Excavating the trenches, as reported by Messrs. Lamb and Hancey, who did the work, cost 40 cents per rod for the smaller and 52 cents for the larger trenches, where the depth did not exceed 4 feet.

The following table of costs is given for the experimental drains and charged to the experimental tract, which is approximately 31.5 acres. The cost per acre was greater than if the whole tract which was actively affected by the drains were considered. As shown later, the effects of these lines reach to one-quarter of a mile down the slope.

Tile:

1,000 feet of 10-inch tile, at \$182.50 per thousand feet.....	\$182. 50
1,012 feet of 8-inch tile, at \$120 per thousand feet.....	121. 44
330 feet of 6-inch tile, at \$60 per thousand feet.....	19. 80
650 feet of 5-inch tile, at \$58 per thousand feet.....	37. 70
2 6-inch on 8-inch wyes, at 72 cents.....	1. 44
	<hr/> \$362. 88

Hauling, digging, and laying:

Hauling tile, 30 tons $1\frac{1}{2}$ miles, at 30 cents per ton mile.....	13. 50
Digging 134 rods, at 52 cents per rod.....	69. 68
Digging 42 rods, at 40 cents per rod.....	16. 80
Laying tile.....	18. 75
Filling trench.....	10. 00
	<hr/> 128. 73

Total cost	491. 61
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The average cost per acre was \$15.60. The above costs were based on ten working hours per day, with labor at \$2 per day, tile layers \$2.50 per day, and man with team \$3 per day.

Results.

The land has been well drained, with the exception of the small spot in the Lamb Brothers' field mentioned above, and is yielding abundant crops. The owners reported yields in 1905-6 which were high for land in the best possible condition. Since drainage, 50 bushels of wheat and 100 bushels of oats per acre have been grown on the reclaimed land. The yield of beets for 1906, on drained land, was 18 tons per acre. The draining of this strip, only one-quarter of a mile wide, has made it possible to break the sod on an equal strip below and to again grow crops there. With the exception of the farmers who were interested in this work but very few are attempting drainage in other fields.

Obstruction of Tile by Roots.

It has long been known that the roots of certain water-loving trees, such as willows, would enter covered drains through the joints and small openings and branch into water roots many feet long, so numerous and close together as to fill the tile, thus obstructing the flow of water. It was also learned by these investigations that alfalfa roots were equally troublesome after a few years. During the fall of 1907 the ground water rose to the surface over the drains in Hancey's and Lamb's fields. The beets which were planted in the fields turned yellow and the ground became so soft that harvesting the crop in that condition was out of the question. Upon removing some of the tiles it was found that they were almost completely obstructed by beet roots. About half of the tile was removed, after which the balance was cleared of roots, and in a short time the ground was dry. During the last season, with the beets removed from about 2 feet on each side of the trench, no trouble resulted.

BOXELDER COUNTY INVESTIGATIONS.

The large valley in which this work was done is irrigated by the Bear River canals. The valley lands have varying slopes, from heavy ones near the foothills down to very light slopes on some of the lower lands. The soils also vary from sandy loams to clay, and are generally very deep, as shown by the cuts of the Bear and Malade rivers. The depths of these cuts are from 50 to 100 feet, and they were supposed to afford excellent drainage. Nevertheless, many of the lower lands became affected by the rise of ground water and alkali soon after the beginning of irrigation. An unsuccessful attempt was made to drain portions of the model farm at Corinne, but not even the locations of the lines are now known. This failure discouraged many, and thousands of acres were abandoned, seemingly without an effort to stay the spread of alkali. The northern portions were considered the only safe lands on the west side.

A survey of the valley, made by the Bureau of Soils in 1904, showed that the lands between the rivers and those above Garland on the west side were the only portions not affected. The area affected continued to increase, and investigations in 1906 showed that the acreage of affected lands in these favored districts had reached approximately 7,000 acres. Even in Riverside, which had been considered perfectly safe from all danger of injury by seepage water or alkali, there was a fine farm of 100 acres seriously needing drainage and showing unmistakable signs of alkali. It was under such conditions as these that the investigations were begun in this valley in May, 1906.

GARLAND EXPERIMENT.

This tract lies 2 miles north of Garland and one-half mile west of the Malade River, the surface of which is 50 feet lower than the tract. The west branch of the Bear River Canal lies one-half mile west of the affected land. The soil is a clay loam underlain by

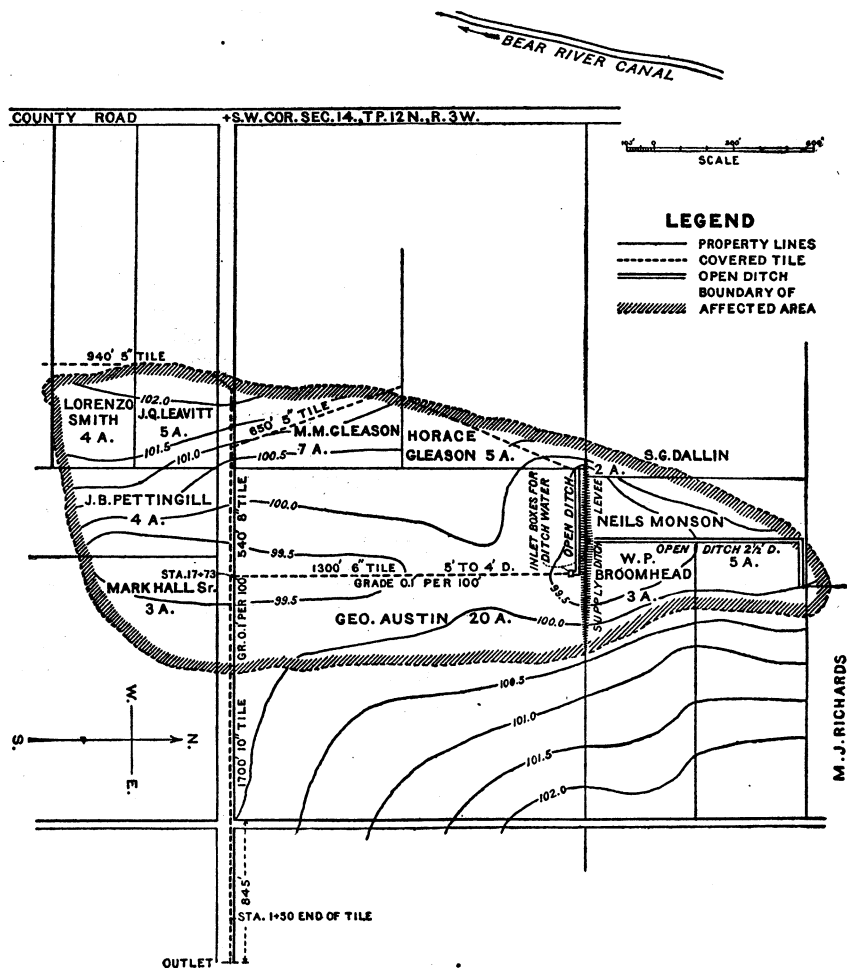


FIG. 3.—Map of field drainage, Garland, Utah.

separate strata of sand and clay and pockets of sand. The affected portion (see fig. 3) contains 60 acres, and is a part of a flat depression extending from Garland to Riverside. The lands between this tract and the canal are sandy and require considerable water.

The source of the water was seepage from irrigation and the canal. Snow and rain water, held by a levee, were also responsible. In its

development this particular case of water-logging and alkali was similar to other cases, and the condition of the land was thought at first to be desirable. The trouble began with a season of subirrigation, and the crops grown were record breakers. This luxuriant growth of crops usually precedes failure due to alkali, and there is little doubt that this tract would have become totally unproductive had not the cause been removed. In this case cropping was delayed for several weeks during the next season because of wetness. Later, beets were planted on most of the land; small spots failed to produce a stand; and subsequently several acres of the beets were drowned by spring rains. It was at this stage that plans for cooperative drainage were begun by the owners. Later the Office of Experiment Stations furnished some assistance, mainly in planning and superintending the work. Eleven farmers, owning lands which would be benefited, cooperated, apportioning the cost according to the areas of their wet lands.

Plans and Construction.

The land within the shaded belt (see fig. 3) shows the wet portion. From the single dotted lines, representing

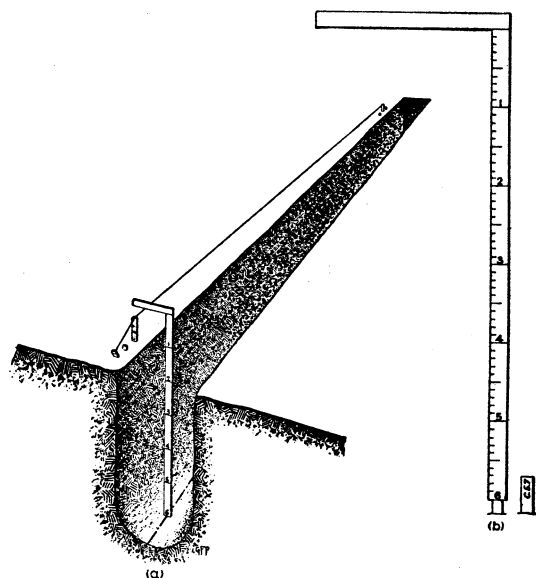


FIG. 4.—(a) Method of grading trench; (b) measuring bar for setting guide stakes and grading.

that both the intercepting and outlet methods were used in laying out the system. A portion of the water was lateral seepage through the porous lands above, which the upper lines served to intercept, while the lower lines provided an outlet for the lowest portions of the tract. During construction small springs were encountered in the trenches in which the water seemed to come from a lower porous stratum.

The matter of properly setting guides for grading the bottom of the trench gave some trouble and, in one instance, resulted in laying the 6-inch line through the Austin field 1 foot above grade, beginning about 100 feet north of the junction with the 10-inch main. This mistake has not yet been rectified. With the hope of making the

method for grading clearer, the following explanation is offered: Two sets of stakes are used, as at Hyde Park, one a grade stake driven to the surface of the ground, from which the levels are taken, and the other a guide stake, on which the cut for that particular station is marked. These stakes should be set 1 foot from the edge of the trench. The long one should be long enough to be driven about 1 foot into the ground and leave about 2 feet above ground. Figure 4a shows the stakes in position, with a wire or string stretched across the tops of the guide stakes parallel to and just 6 feet above grade. The guide stakes have been driven until the tops are above the grade stakes an amount equal to the length of the measuring bar minus the cut at the station. If the measuring bar be graduated, as shown, from

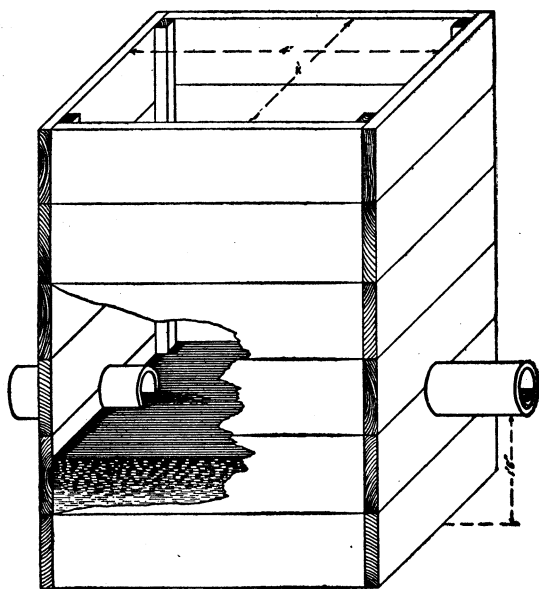


FIG. 5.—Sand trap and surface inlet.

the top down, the guide stakes may be set by driving them down to a level of the cut reading on the rod when the rod rests on the grade stake, as in figure 4b. With the rod held vertically, the lower end is at true grade when the horizontal arm touches the wire.

Construction difficulties were encountered when the work reached the wetter portions of the field. The usual soft spots were encountered, with water entering in relatively large streams.

A firm foundation for the tile was necessary, so some gravel was thrown in. Later experiments proved that 1-inch by 6-inch boards were more convenient. Fine sand and silt gave considerable trouble by flowing in at the joints and settling in the tile, and to prevent this a few joints were wrapped with tarred paper. Sand and gravel would have stopped this and been better adapted to the needs. Later, a sand trap, shown in figure 5, was put in at the junction of the south branch and the main. This box was made 4 feet by 4 feet inside and extended 18 inches below the grade of the tile. A box was also set in just above the lower place of trouble, where flushing water was turned in to clean out the tile. A large portion of the sediment settled in the larger

tile below. Another sand trap should have been put in at the junction of the 8-inch and 10-inch tile on the main line.

Cost.

Tile:

1,700 feet of 10-inch tile, at \$181.10 per thousand feet-----	\$307. 87	
540 feet of 8-inch tile, at \$125 per thousand feet-----	67. 50	
1,300 feet of 6-inch tile, at \$74 per thousand feet-----	96. 20	
2,775 feet of 5-inch tile, at \$50 per thousand feet-----	138. 75	
		<hr/>
		\$610. 32

Labor:

Labor for 384 rods, at \$1 per rod-----	384.00	
Open ditch work-----	18. 00	
		<hr/>
		402. 00

Total cost-----	1, 012. 32
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The average cost per acre was \$16.87, including the 1,700 feet of 10-inch outlet. Wages were \$2 to \$2.50 per day of nine hours.

Results.

The resulting improvement in this tract, even before the system was entirely finished, was very marked. The next season this land was planted as early as the higher lands and produced just as good crops. Not a trace of alkali showed, where it was plainly evident the year before. There is no question that these 60 acres, and probably more, would have become entirely unproductive within a few years, but with drainage they are producing as well as those unaffected.

POINT LOOKOUT EXPERIMENT.

This tract is located about 5 miles southwest of Garland and $3\frac{1}{2}$ miles west of Tremonton, on the county road, and is fairly typical of the majority of lands in this valley which have lost their productivity of late years on account of seepage water and alkali accumulations. The soil is a clay loam with a mushy water-bearing stratum, about 12 inches in thickness, between 4 and 6 feet below the surface. The tract was brought under cultivation in 1897. The first crop was 42 bushels of wheat per acre, and those following were good until 1902. Since then the tract has not paid expenses. Investigations were begun here in September, 1906, at which time there were large dark-brown alkaline spots throughout the field, on which nothing grew. Alkali was evident in other spots from the familiar white efflorescence.

Plans were made after careful preliminary surveys of surface slopes and examination of subsoil conditions (fig. 6). The intercepting method was used principally, but some parallel lines through the worst portion seemed necessary, as need for considerable leaching for the removal of alkali was expected. The tile were laid from 4 to 5

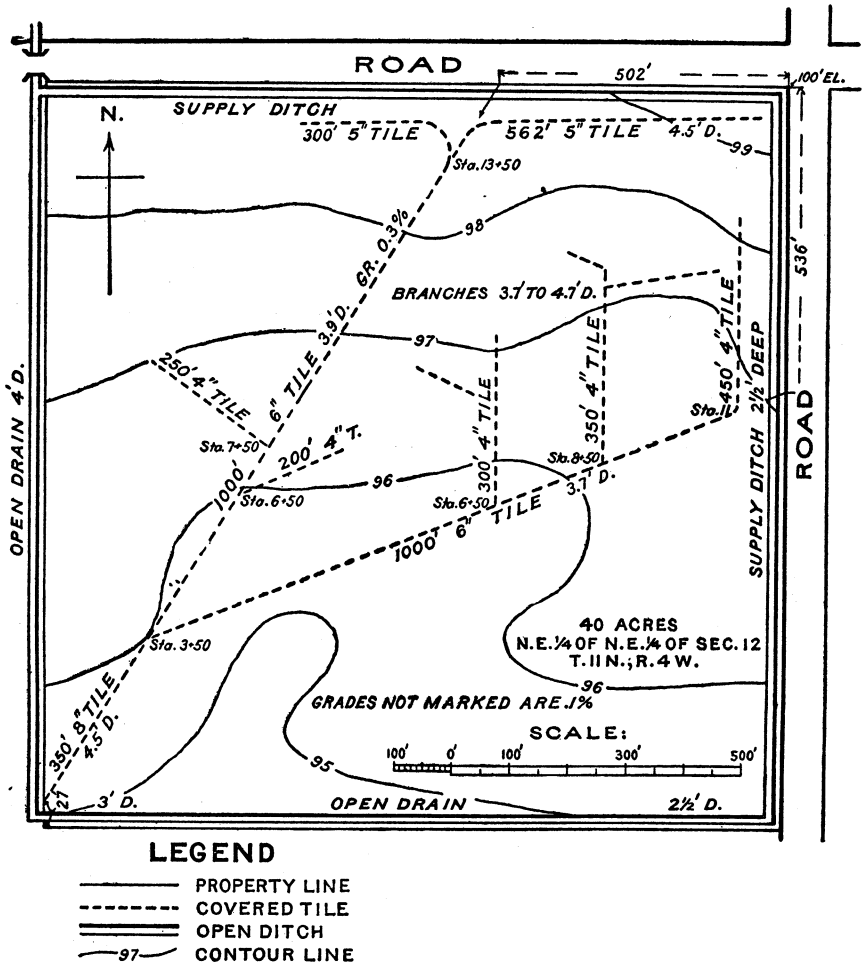


FIG. 6.—Plan of draining Getz field, Point Lookout, Utah.

feet deep, cutting through the close subsoil into the more open water-bearing stratum. For field map and system of drains see figure 6.

Construction and Cost.

The most important lesson to be learned from the field construction is that the cost of such work can be reduced one-third to one-half by experienced laborers. The tools used for digging and grading were

ditching spades and tile scoops. The work was done by experienced farmers during December and January, 1906-7.

Tile:

2,100 feet of 4-inch tile, at \$40.15 per thousand feet.....	\$84. 32
812 feet of 5-inch tile, at \$55.22 per thousand feet.....	44. 84
2,050 feet of 6-inch tile, at \$7.85 per thousand feet.....	161. 64
350 feet of 8-inch tile, at \$133.35 per thousand feet.....	46. 67
Extras, wyes and tees.....	3. 41

Total.....	\$340. 88
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Digging and laying:

85 days, at \$2 per day of 9 hours.....	170. 00
Hauling tile $\frac{1}{2}$ mile, 7 days, man and team, at \$3 per day, 70 cents per ton.....	21. 00
Filling trench, man and team, 3 days, at \$3 per day.....	9. 00

Total.....	200. 00
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Total cost	540. 88
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The average cost per acre was \$13.52. The labor cost was approximately 4 cents per linear foot, or 65 cents per rod.

Results.

The land has been thoroughly drained excepting a few acres in the southeast corner, which remained a little damp after the wet spring of 1907. That spring was an unusually wet one, but this farm as a whole was in better shape for early spring work than the best lands in the same neighborhood. The wet spot above mentioned was probably caused by lateral seepage from the land on the east. Notes taken during the spring and summer show that the tract responded to drainage remarkably well. Early in the spring it showed improvement, and to all appearances was free from alkali. Later it was planted to oats, continuing to improve and yielding 35 bushels of oats per acre. No signs of the alkali spots have been observed, and as a consequence it has attracted considerable attention. For the season of 1908 the Getz tract produced 45 bushels of oats per acre and an excellent stand of young alfalfa.

The influence of the experiment has already been felt. Early in the spring of 1907 other farmers came to see it, and straightway ordered tile. They received some assistance in locating and laying out lines. Mr. P. A. Hansen, of Elwood, laid some tile through a small orchard and on the advice of this Office strung the tile with a galvanized wire, by which a cable and root cutter can be worked if roots cause trouble, as they are expected to do. A steam traction ditcher is now in use in this district and a tile factory is in operation.

INVESTIGATIONS IN WEBER AND DAVIS COUNTIES.

The work done in these counties was with the seepage and alkali conditions on the bench lands between Ogden and Layton. The soil has probably been brought down by the Weber River, and is classified, in a survey by the Bureau of Soils, as a fine sandy loam. The higher portions through which the canal runs, and which are also irrigated, contain considerable gravelly soil. Until recently this section, called the "Sand Ridge," was not irrigated. Fall wheat was grown successfully without irrigation. The soil and climate are particularly adapted to vegetable gardening and fruit. Bare land in good condition is worth \$150 per acre and orchard land much more. Several years ago some seepage began to show on the lower slopes. The number of places affected increased, and they were not confined to any particular slope or level. The total area of such lands grew rapidly, and alkali made its appearance. In 1906 the area affected was estimated at 2,000 acres, and has increased since then.

ROY EXPERIMENT.

This experiment was made on the J. H. Hobson farm, 2 miles west of the Oregon Short Line Railroad station at Roy. The farm lies on a series of narrow benches, having a difference of elevation of from 6 to 10 feet. The soil is a clay loam with sandy spots, underlain by a tough clay subsoil to a depth of 4 feet, beneath which lies a 12-inch stratum of water-bearing sand. There were several spots found where the sand was continuous from the surface to the water-bearing sand below. The strata are not in a blanket form at an even depth from the surface, but horizontal and at different depths on the various benches. The soil seemed to have formed over the edges of the benches compactly enough to hold the water in the sand and make it rise to the surface above. Some hardpan was encountered at a depth of 4 feet near the sand trap (fig. 7), at the junction of the main and the west 5-inch line. It is the typical calcium carbonate, lake shore hardpan, which is readily penetrated by roots and is fairly pervious to water.

Seepage water had appeared at the bottom of the steeper slopes and spread in places 40 rods or more down the slope, bringing an accumulation of alkali. This farm had been known generally for some time as one badly affected with alkali. It had come into the present owner's hands in 1905. When he discovered that the farm needed draining he immediately set to work. Later in the same season—1906—he sought the assistance of the Office of Experiment Stations.

Plans and Construction.

The lines of tile on the upper bench, shown on the contour map of the field (fig. 7), were laid in the sand stratum with a view of affording an outlet of the least resistance and one that would keep the water the lowest. The lower bench lines were put in where the water

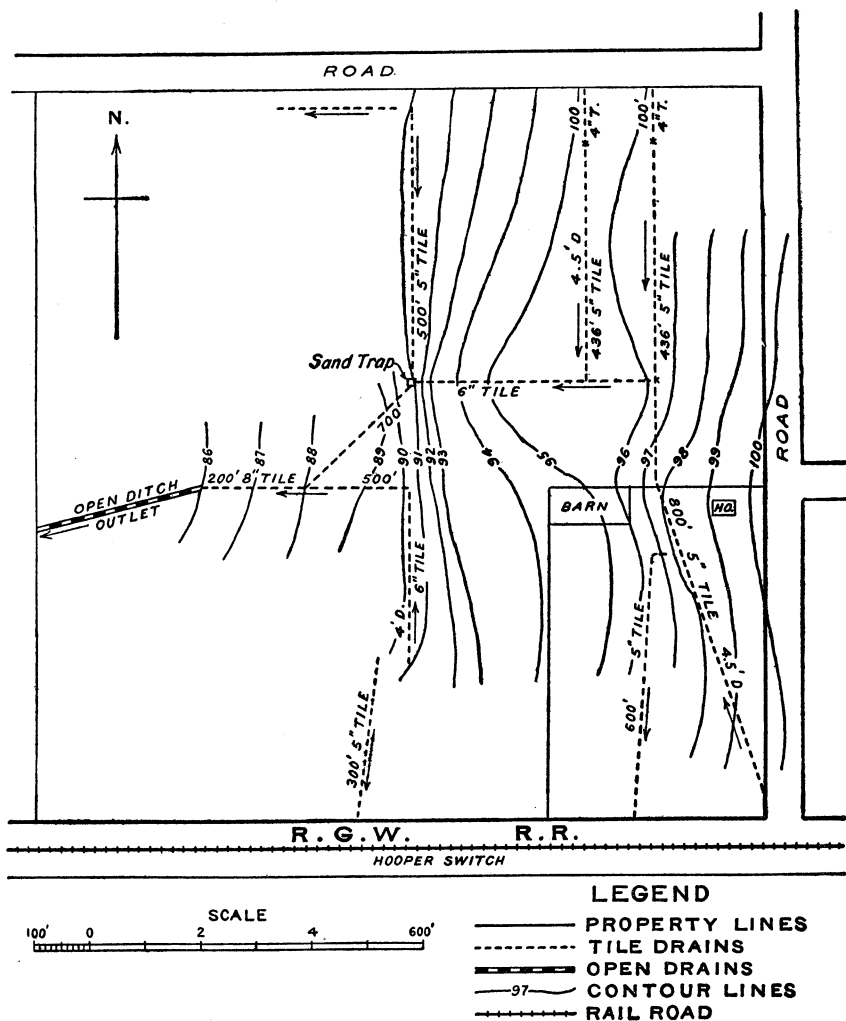


FIG. 7.—Plan of draining Hobson field, Roy, Utah.

cropped out. The depths and sizes of tile are shown on the map. After the lines were staked out and before deciding on the grades auger holes were put down every 200 feet and the depth below the grade stakes to the top of the sand determined. Then the grade was made so as to just cut through the clay subsoil into the sand stratum.

Nearly all of the tile were laid on 1-inch by 6-inch boards to keep them in proper alignment.

A portion of the main line was plowed and scraped out, to a depth of 2½ feet, with a narrow slip scraper and one horse. A section of trench 500 feet long was left open during a cold snap, and before the tile were laid the banks broke off in great slabs from 6 inches to 1 foot in thickness, and up to 10 feet long. These had to be broken with pick and bar, as they thawed very slowly. The work was done at odd times by the owner and it was not practicable to get exact data of the cost of the labor.

Cost.

Tile:

200 feet of 4-inch tile, at \$34.20 per thousand feet-----	\$6.84
3,072 feet of 5-inch tile, at \$46.30 per thousand feet-----	142.23
1,200 feet of 6-inch tile, at \$67.80 per thousand feet-----	81.36
200 feet of 8-inch tile, at \$113.80 per thousand feet-----	22.76
3 wyes-----	1.75
	<hr/> \$254.94

Lumber laid under tile:

475 feet b. m. 1-inch by 6-inch by 14-foot lumber, at \$30 per M-----	14.25
1,333 feet b. m. 1-inch by 6-inch by 14-foot lumber, at \$29 per M-----	38.65
954 feet b. m. 1-inch by 6-inch by 14-foot lumber, at \$28 per M-----	26.71
	<hr/> 79.61
Labor cost, approximately 75 cents per rod-----	212.25
	<hr/> 546.80
Total-----	

Average cost per acre, \$13.67.

Results.

That satisfactory drainage was obtained is evidenced by the fact that the ground would hold up loaded wagons any time during the spring, while before drainage, horses were mired while plowing as late as June. As a consequence of the draining, farming operations were possible earlier in the spring of 1907 than on neighboring farms which the owners thought needed no drainage. Though there were some spots where crops failed on account of alkali during the season, the improvement was easily noticeable. Very fine peas and potatoes were grown in 1908 on portions of the upper bench, which had been bare before drainage. The neighbors, who were skeptical before, now say that the work has already enhanced the value of this farm \$1,000.

OGDEN EXPERIMENT.

The Wasatch Orchard Company undertook some drainage on their factory farm 1 mile southwest of Ogden, in 1907, under the direction of this Office. The soil is somewhat like that at Roy, with more hard-

pan, which is nearer the surface than at Roy. In the southeast corner this hardpan was only $3\frac{1}{2}$ feet from the surface. The situation was probably typical of a number of similar areas in this district, and the results obtained here should be worth a great deal to farmers confronted with the same problem. Alkali and seepage water had been giving trouble for a year or two, and several acres were barren as a consequence. The accompanying map (fig. 8) is self-explanatory.

Plans and Construction.

In order to get the total available soil depth, the tile were laid into the hardpan about 6 inches. The digging in this formation showed

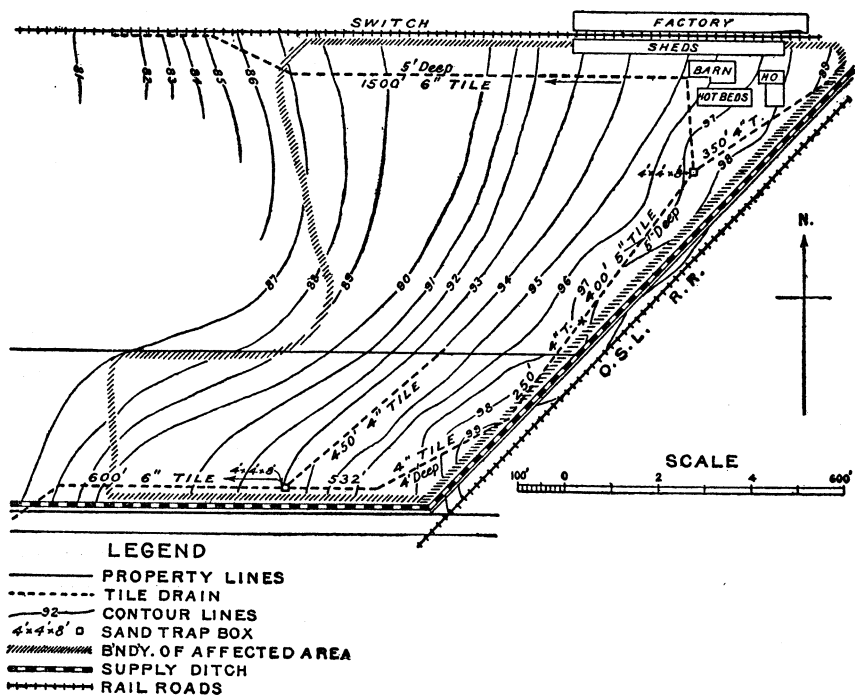


FIG. 8.—Plan of draining Wasatch Orchard Company's field, Ogden, Utah.

that it was very porous and carried considerable water. The work was done during the summer, and much water was obtained, though the surface of the farm was dry. In the wettest portions the water was from $2\frac{1}{2}$ to 3 feet below the surface.

Cost.

The cost of this work was much more than it should have been. Labor was high and very scarce. City sewer-trench diggers were employed by the day; besides this, unnecessarily large quantities of gravel were placed around the tile.

Results.

The wet portions were well drained, and Superintendent Van Allen, who was somewhat doubtful at first, is now well pleased with the results. Good crops of peas and alfalfa were grown during the last two seasons on this land, which would not grow peas at all before drainage.

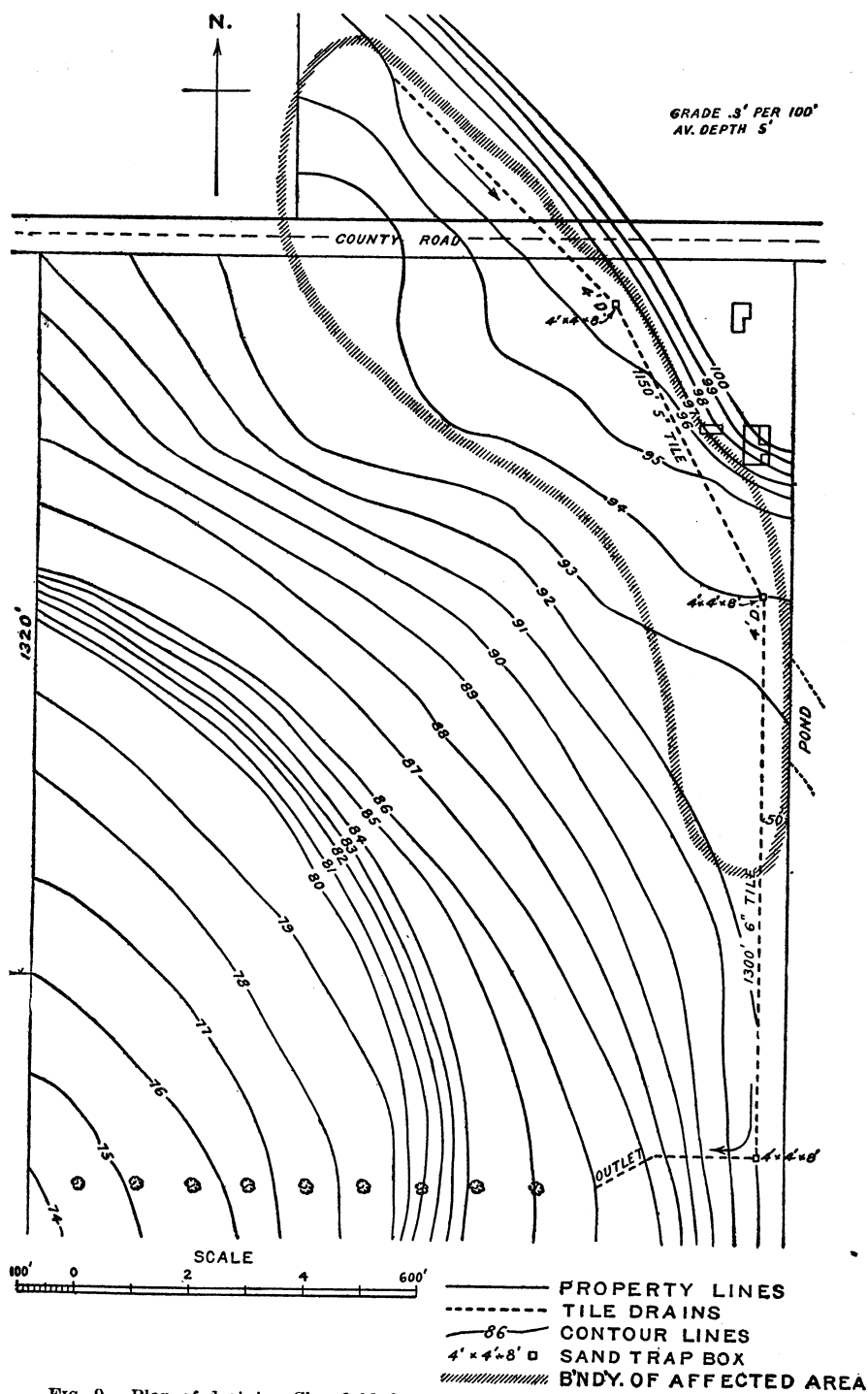
CLEARFIELD EXPERIMENT.

This work was done by the Clearfield Orchard Company on their orchard about 1 mile southwest of the Clearfield station, on the Oregon Short Line Railroad.

The soil is a fine sandy loam with a subsoil made up largely of fine sand, though on the Sand Ridge the soil formation is different from that at Roy and Ogden. Here it seems to have been formed or shifted about by winds, and small sand hills, knolls, and depressions are often found on the same farm.

The history and extent of the injury are practically the same as for the other places mentioned above. Several years before this work was begun an attempt was made to drain two small benches on the near-by Bishop White farm. On the upper bench a drain from 7 to 9 feet deep was laid, which was expected to intercept the seepage on both levels, but it failed to do so. A portion of this line was laid well up on the slope at the upper end to get more grade and failed to drain the narrow bench immediately below. Fine sand was encountered, but the tile were covered with gravel and sand boxes put in. This work was well done, but very expensive, and consequently discouraging. The Clearfield Orchard Company's orchard, immediately below, became affected in 1906, so that the leaves seemed to burn on a number of otherwise healthy trees. This was thought to be due to the effects of the alkali, which showed rather plainly on the ground. Several acres became so wet that spraying could not be done. The next spring the owners asked for advice, and the work described below was done, the Office making the plans.

The map (fig. 9) shows the location of the drain and other data. At the date of examination, the pond noted on the side contained 2 feet of water just above the division fence and stretched out to one-quarter of a mile long. The water was kept out of this farm by a dam, but the seepage, naturally, flowed through the soil to the orchard. This was not the only source of seepage, so the line was extended through the upper slope of the affected ground northwest of the pond. The minimum depth was placed at $4\frac{1}{2}$ feet in the swale opposite the pond and the maximum $6\frac{1}{2}$ feet in the ridge below the pond. The object of running the outlet line so far along the fence was to secure water for the wind-break trees.



Field Construction.

The digging was attended with difficulty on account of very fine sand and water and the inexperience of the laborers, which resulted

in the tile being laid 6 inches above grade. When nearing the orchard, the trench was opened a few days before tile laying began, causing the land to become sufficiently dry to permit the distribution of tile by team over ground which was previously soft and miry.

Beneficial Results.

The wet ground has been very well drained, excepting a small area just west of the house and barn. From the results obtained it seems that the line of tile should have been laid about 100 feet farther down the slope. The company will lay an additional branch through this part during the coming season. The trees

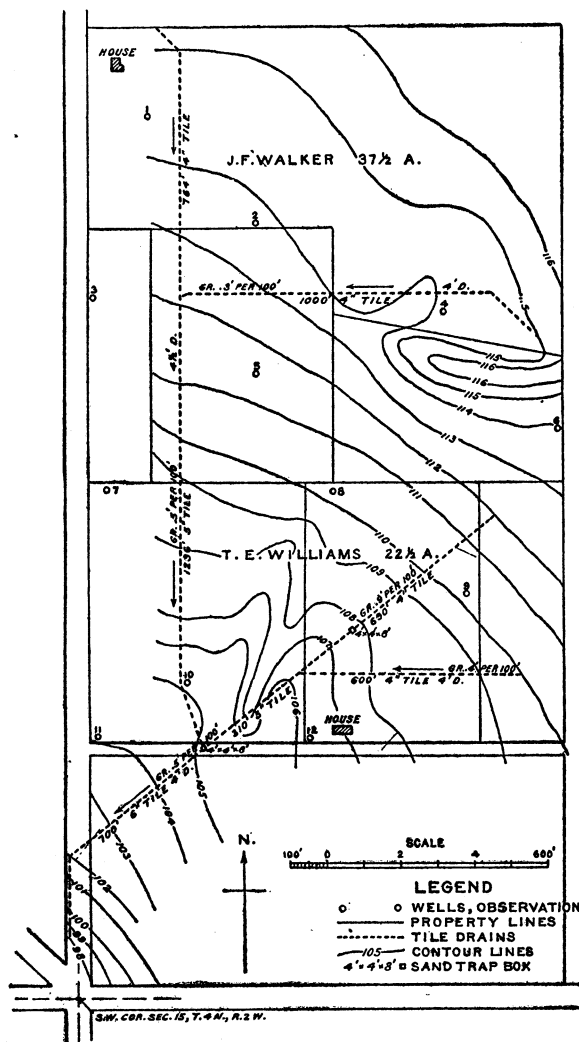


FIG. 10.—Plan of draining Walker and Williams fields, Syracuse, Utah.

have apparently recovered, and the foliage and fruit were good last year. Plowing and other necessary operations are performed without trouble.

SYRACUSE EXPERIMENT.

This work was done on the adjoining farms of Messrs. J. F. Walker and T. E. Williams, some 3 miles down the slope from the Clearfield farm, under practically the same soil, subsoil, and water conditions. It was undertaken upon the recommendation of the Office, and completed according to the plans furnished. There was considerable water in the spring time and some alkali had made its appearance, both of which had seriously interfered with cropping. Water from artesian wells is stored in small reservoirs and used for irrigation. The seepage loss from these reservoirs was considerable and was thought by some to be the whole cause of the trouble. Later observations, however, pointed to two sources—this reservoir seepage and also the irrigation on higher lands. For plans, grades, and slopes, see figure 10.

Results.

The system is working well, but extensions into wet spots are needed on both farms. Extensions are already begun on the Walker farm, and both owners are well satisfied with what has been done. Other farmers in the same neighborhood are now taking up the work.

EMERY COUNTY INVESTIGATIONS.

Emery County is in the eastern part of the State, in what is known as the "Colorado Plateau." The soil is an alluvial sandy loam, underlain at various depths by shale. Mechanical analyses of the soils on the Huntington experimental tract show that the proportion of silt ranges from 28 to 55 per cent and that of very fine sand from 23 to 42 per cent. The upper layer of shale, whether on the surface or below, is a very tenacious clay. A foot below, the shale becomes looser and at several feet below is in large pieces, open enough to allow the free flow of water.

When these lands were first brought under cultivation they were remarkably fertile and, to all appearances, would never need draining. Within a few years spots of wet land began to appear in the fields, alkali accumulations followed, and the spots spread until whole farms had to be abandoned. Such conditions abounded throughout the valley. There was some talk of draining, but the close proximity of large gullies or arroyos to such lands, without any beneficial effect, made it seem impossible to drain, so the water-logging of farms continued and farms and portions of towns were abandoned until in 1904 it was estimated that 30 per cent of the land which had been under cultivation was at that time abandoned. As the trouble was increasing, it was only a question of a few years before whole tracts would have to be abandoned entirely.

HUNTINGTON EXPERIMENT.

It was with these prospects confronting the people that they applied to the State station for help. The work was begun in 1904, by making soil water observations at Huntington, and continued the following year by some construction. This Office and the State co-operated with the Bureau of Soils, Emery County, and Mr. E. L. Geary in making an experimental test on the farm of the latter.

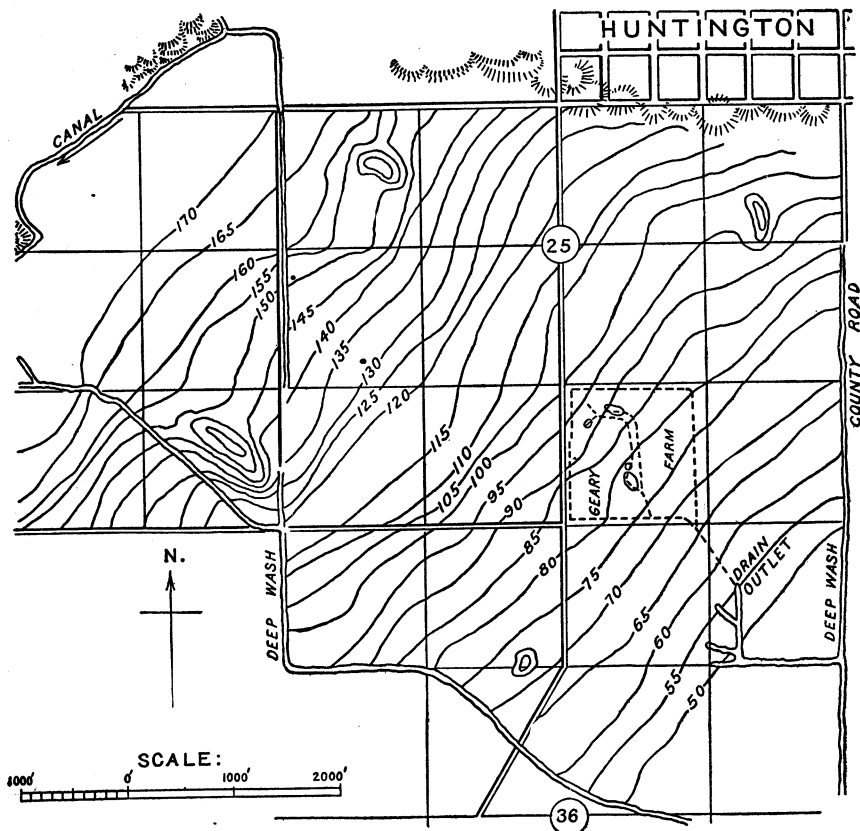


FIG. 11.—Field contour map showing location of Geary farm.

This tract was typical of the lands of the valley, and contained portions in all the varying stages of deterioration. The soil survey also showed that white alkali, ranging from less than 0.2 per cent up to 3 per cent, existed in the surface foot and to 6 feet deep. For the location of the Geary farm, with reference to the surrounding fields, see figure 11. Preliminary examinations of this farm were made, including a thorough subsoil survey by means of test pits, auger borings, and probings with a steel rod to a depth of 15 feet. The subsoil sur-

vey brought out the relation of the shale hardpan to the source of the water and alkali. This formation lay in ridges and knolls under an almost uniformly sloping surface. The two bogs shown on the farm map, figure 12, were directly over two of these shale knolls, and it

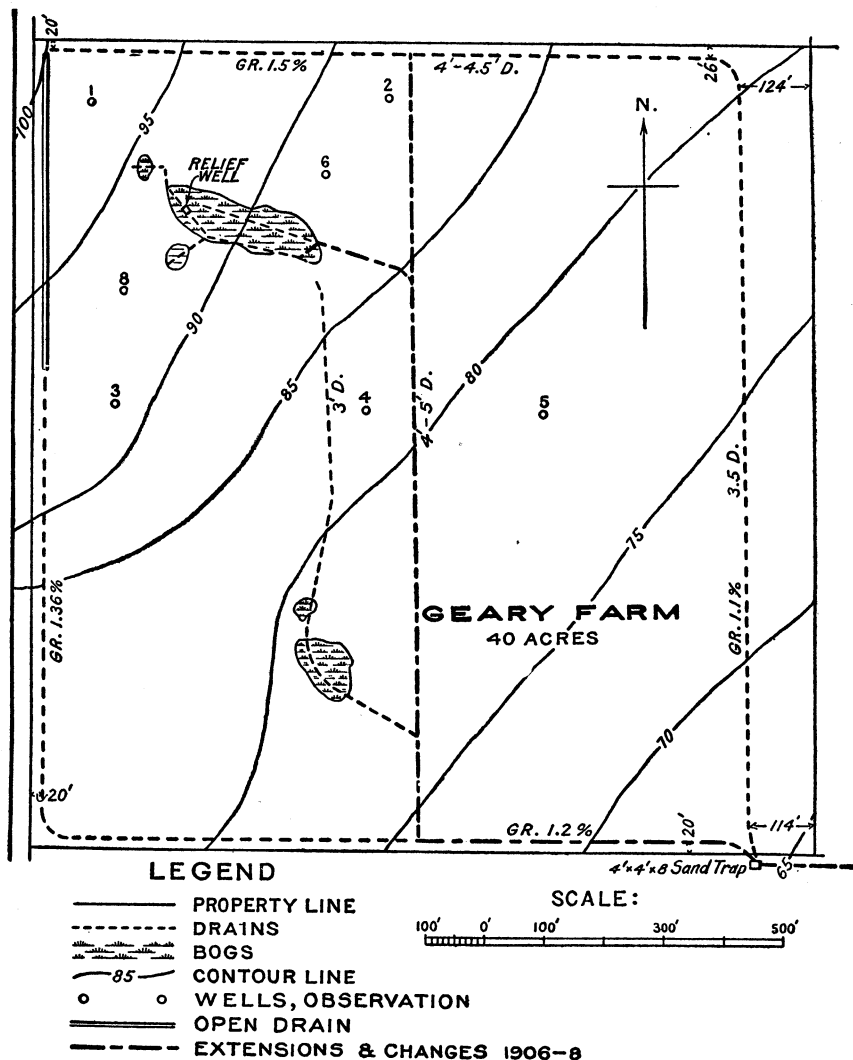


FIG. 12.—Plan of draining Geary farm, Huntington, Utah.

was shown that these carried to the farm, from some distant source, water highly charged with alkali. Some lateral seepage came from neighboring farms, but the bulk of the water which kept these bogs miry for rods around and which kept the soil saturated, was undoubtedly from the first source. Water stood on the surface within a

few feet of a deep gully or arroyo on the south of the farm. It was clearly evident from this and other indications that the intercepting method of drainage would be necessary.

Plans and Construction.

Draintile for covered drains was out of the question, on account of high freight rates and the distance from the railroad. Lumber was the next best material, and as this could be readily obtained it was chosen. Boxes were made of 2-inch by 12-inch plank for the outlet, and of 1-inch by 8-inch boards for the laterals, without bottoms in firm ground, and with bottoms for soft ground. (See fig. 13, *a* and *b*.)

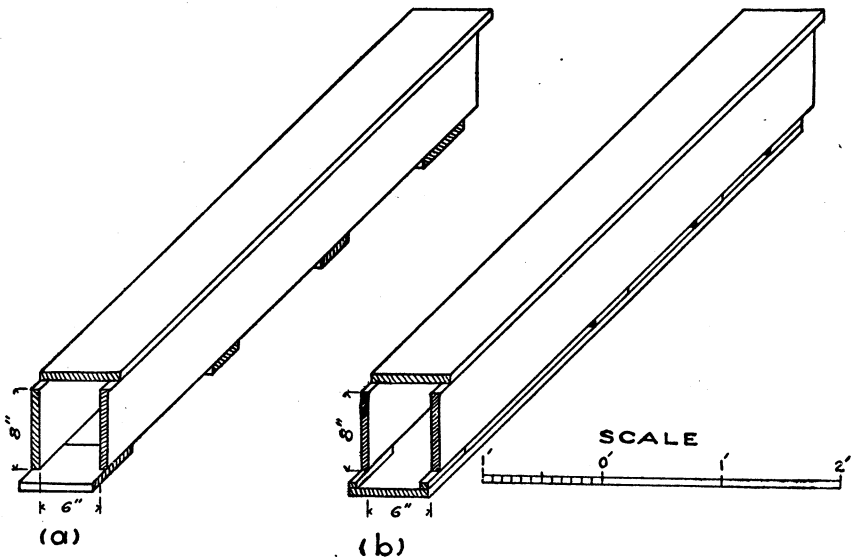


FIG. 13.—(a) Box drain for firm ground; (b) box drain for soft ground.

A line was cut into the bogs with the object of catching the water at a safe depth below the surface and conducting it away from the field. The upper drain of the central areas, shown on the farm map, was the first one constructed. The outside lines were laid as a protection against lateral seepage.

Some of the trenches were dug before the lumber arrived, and a heavy rain storm did considerable damage by causing the sides to cave in. About half of the digging was in such bad condition that it was impossible to get the boxes laid as deeply as planned, and in several cases the mud was pressed into the boxes continually. Flushing them with water was useless, but by cutting the boxes into short sections and keeping them laid and covered to within a few feet of the digging, some headway was made. The boxes were laid about

3 feet deep between the bogs, making it possible to get into the upper bog 6 feet deep. Here considerable water was encountered and from a well 4 feet deep (see fig. 14, *a*) in the bottom of the trench enough water rose and ran into the drain to give a head of $1\frac{1}{2}$ inches over a 6-inch rectangular weir. This stream has been constant and the total discharge of the system has been nearly constant, except when affected by immediate irrigation. The discharge was measured at the outlet for a year, and gave an average head of 1 inch over a 12-inch rectangular weir and is still running. Most of this comes from the bog holes, and is highly charged with alkali. When near-

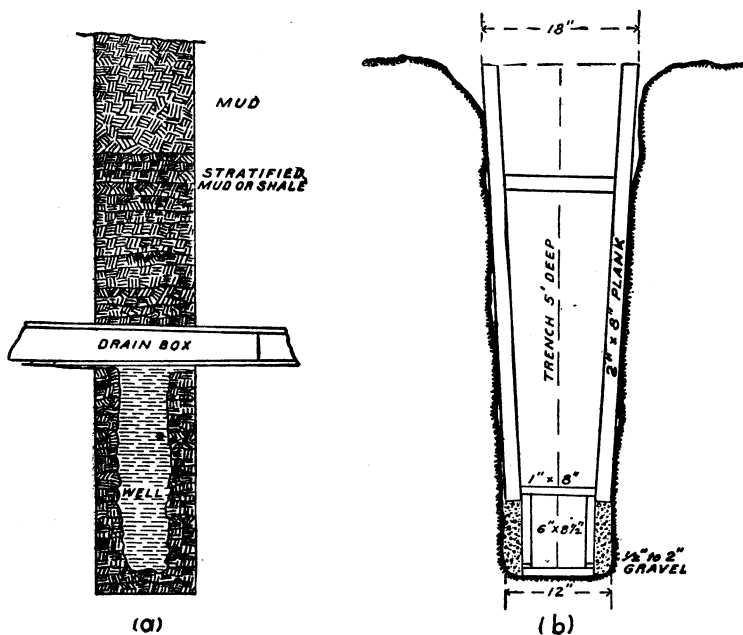


FIG. 14.—(a) Relief well on Geary farm, Huntington, Utah; (b) method of laying box drain, with gravel filling and plank sheathing, through soft ground.

ing the bogs every contrivance failed, and water was turned in the trench to cut out the soft muck, which was run out over the field below.

Cost.

Where the ground was dry or firm and the depth not over $4\frac{1}{2}$ feet, digging cost 40 cents per rod. Greater depths, up to $5\frac{1}{2}$ feet, cost 55 cents per rod. The digging in shale was heavy work, and cost as much as \$2 per rod for short sections. The average cost for the first central line, including shale and very soft mud, was approximately 90 cents per rod.

The cost of making boxes with open bottoms was about 10 cents per rod. Boxes were laid and blinded for 20 cents per rod, and filling cost approximately 8 cents per rod.

The total cost of \$808.67 works out 11½ cents per linear foot and \$20.21 per acre for the tract, though there is almost half as much more land drained outside of the field.

Extensions.

A portion of the west-side drain protecting the northwest corner became obstructed during the winter of 1905-6 and attempts to remove the obstruction proved unsuccessful. This section of the drain had been provided with boxes open on the bottom. Straw was thrown in the bottoms of the trenches before laying the boxes for the purpose of preventing the soft mud from squeezing into them. It seems that the weight of the soil caused it to flow into the boxes in spite of the precaution taken. As it was impracticable to remove these boxes, Mr. Geary decided to cut an open ditch, paralleling this section, between it and the fence. This ditch was washed to about 5 feet in depth; and plans were made for laying boxes in the same, providing bottoms for the boxes and filling in the sides with gravel. (See fig. 14, *b*.) The laying of boxes in this section has not been finished, owing to other troubles.

During the same season (1906) a change in the central line for conducting the water away from the bogs was planned and late in the same year was partly finished. The necessity of putting another line through here was due to the shallowness of the first central drain. When this first line was laid it was impossible to get the boxes to a greater depth between the bogs than 3 feet. This depth was not sufficient to prevent excessive evaporation along the line, but the drainage of the bog had dried out the land below, so that digging 5 feet deep was now possible. It was decided to put in this line, as shown on the map (fig. 12, p. 27), in about the center of the farm, with the object of providing a better outlet and diverting the water from the upper bog into this drain. This line was completed out to the bend immediately below the bog.

No further work on these extensions was done during the year 1906, and cropping operations were carried on during the summer of 1907. A greater part of the farm was planted to oats, and care was taken in irrigating to prevent any washing by surface water. Irrigation was carried on immediately over the drains on the south side. The surface water was kept out of the drains during irrigation, but the soil continued to run into the boxes for several days after the application of water, resulting in the complete obstruction of the drains. These obstructions caused the drainage water which was

coming from the two bogs to rise to the surface and to seep away into the soil during the balance of the summer. There was no other outlet for this water, so repairs were undertaken in May, 1908.

Subsequently, all boxes were provided with bottom boards (leaving openings of one-fourth inch, as in fig. 13, p. 28) and packed with sand and gravel along the sides. As it was impracticable to dig a new line anywhere near these portions on account of the excess of water, an attempt was made to uncover the boxes on the south side of the farm by using surface water and washing the earth through the outlet ditch into the large arroyo below. This attempt resulted in obstructions forming in the outlet drain which made it necessary to uncover these boxes and remove them. After washing out the soft mud and providing an outlet for the drainage water, work on relaying the boxes was resumed. Boards 1 inch by 12 inches were nailed onto the bottoms of the outlet boxes, and they would have been relaid in the original outlet line had not the owners on the south proposed to cut an open ditch running east from the southeast corner of the Geary field to the county road. An outlet for the drainage of this system was offered, and 200 feet of boxes was laid along that line as a precaution against erosion of the ditch into the Geary farm. The balance of the closed boxes from the outlet line were laid on the south side. A new drain was constructed between the south side and the new central-line work laid in 1906. The necessity for this change was caused by an obstruction in the short diagonal section. After finishing the south-side repairs the completion of the central line was taken up. This line was extended through to the north side to protect the land below and to furnish an outlet through the reconstructed drain for water coming from the northwest side. The line extending northwest into the bog, with a branch for cutting the water of the upper drain over into the lower drain, was next taken up. All of the work done during the season of 1908 was under very difficult and discouraging conditions. The expense has been unusually high, and the complete reclamation of the tract is not yet attained. Three-fourths of the farm was planted to oats and a fair crop grown on possibly half of the farm. The barrenness of this field is slowly but surely giving way to improved conditions.

The total cost of making these extensions and repairs, including the work in 1906, was \$557.45. This gives a cost per acre of \$13.94, which, added to the original cost of \$20.21, makes \$34.15 per acre up to date.

In conclusion, it may be safely said that unless special precautions are taken in limiting the openings and protecting the same by gravel and sand, the use of covered drains in these soils will not prove very satisfactory. In addition to these precautions, irrigation must not

be carried on directly over the drains, and where irrigation ditches must cross the drainage lines flumes should be provided. There is no question that this farm has been greatly improved, as evidenced by its appearance and the crops now growing. The obstructing of the drains and consequent rise of ground water on the south side of the farm also injured the Johnson tract on the south. The cost has been higher than land values would warrant in this particular case, but there is every reason for believing that success within the proper economical limits will be attained. Cultivation and irrigation will be carried on in the same way as it has been, and the Office will continue to watch the operation of the drains carefully until the experiment is completed.

SEVIER COUNTY INVESTIGATIONS.

The Sevier County work was done near Richfield, in the Upper Sevier River Valley, which extends from Gunnison on the north to Elsinore on the south. The valley is surrounded by high mountains, and although the rainfall is light (less than 9 inches) the supply of irrigation water is good.

The soil of the valley is a rich red clay, and was originally very productive. The seepage of surplus irrigation waters, however, soon began to destroy the lower lands, which, as is generally the case, were the most productive. Boggy places were formed and alkali made its appearance, until eventually large acreages were abandoned. The destruction has continued to spread, driving the farmers to higher lands, until it now becomes evident that unless the march of the alkali be checked total abandonment will be the ultimate result. The soils are generally charged with alkali, more than 37,000 acres containing from 0.2 per cent to 3 per cent. Richfield, although near the upper end of the valley, has its share of these troubles and is fairly typical. About 15,000 acres in its immediate locality are in need of drainage.

RICHFIELD EXPERIMENT.

This experiment was made on a tract of land between Richfield and Venice, just above the Vermilion Canal, by cooperation between the Office and the owners, William and Junius Ogden and William Gardner.

The tract has a general slope of about 0.5 per cent toward the southeast. The very highest portion only was producing crops, the balance being covered with salt grass. Some spots were entirely bare and flooding did not seem to effect much improvement. The source of water was lateral seepage from higher lands, flowing through a sand substratum.

Plans and Construction.

Two parallel lines of tile 600 feet apart were planned, one along the upper slope to intercept the water and the other below, each to have short branches to tap particular spots and both having a common outlet, tiled under the canal and then open to the river. The average depth was 5 feet, the grades being from 0.3 to 0.5 per cent, in order to carry away the fine sand, etc. Plans are shown on the map (fig. 15). The open-trench outlet was proposed to reduce first cost, but was later replaced with a 10-inch pipe drain.

The open trench was first dug, and then the work of placing the tile under the canal was undertaken. A stream 15 feet wide by 1 foot deep was flowing in the canal and could not be shut off, so it was necessary to do the trenching and tile laying in sections surrounded by an improvised cofferdam, built of sand bags, extending partly across the canal. Sewer pipe was used, and the joints cemented to prevent leakage from the canal.

The digging was done by inexperienced laborers, and some little trouble resulted. In one case 400 feet of trench had been excavated and was left open from Saturday until Monday morning, with the result that seepage caused the sides to cave in and made the waste material so sloppy that an

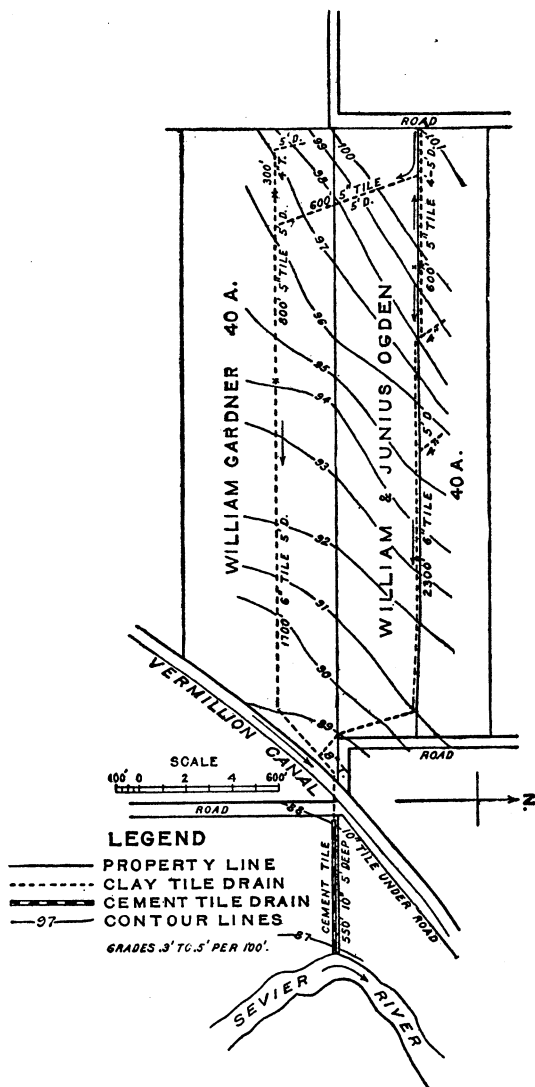


FIG. 15.—Plan of draining Gardner and Ogden fields, Richfield, Utah.

attempt to remove it was unsuccessful and an offset line had to be constructed. Another difficulty was the settling of fine soil particles in the tile, requiring them to be flushed out, which made work in the trench very disagreeable. In most of the work the back filling had to be kept up within a few feet of the excavating.

The best results were obtained by using a team of three diggers, each taking out a spading, the first keeping less than 2 rods in advance of the finished trench and the last grading the bottom as he removed the final spading. A tile layer accompanied the diggers and kept the tile laid and blinded to within a few feet of the diggers.

Cost.

Tile was shipped from Salt Lake at a freight cost of 24 cents per hundredweight. Labor was expensive and hard to get, so the final cost was rather high. Day labor cost \$2 for eight hours.

Tile f. o. b. Richfield:

1,000 feet 4-inch tile, at \$47.50 per 1,000 feet-----	\$47. 50
2,000 feet 5-inch tile, at \$71.25 per 1,000 feet-----	142. 50
4,000 feet 6-inch tile, at \$92.50 per 1,000 feet-----	370. 00
150 feet 8-inch and 10-inch sewer pipe, seconds-----	27. 42
50 feet 10-inch sewer pipe, at 49 cents per foot-----	24. 50
6 feet 6-inch tees and 1 8-inch wye-----	2. 20
10 barrels cement for 600 feet 10-inch tile-----	50. 00
Total-----	<u>\$664. 12</u>

Hauling, digging, laying, etc.:

Hauling 50 tons, 2 miles, at 25 cents per ton mile-----	25. 00
450 rods trenching, at 60 cents per rod-----	270. 00
450 rods tile laying and filling, at 25 cents per rod-----	112. 50
25 days' labor, making cement tile, at \$2 per day-----	50. 00
Total-----	<u>457. 50</u>
Total cost-----	<u>1, 121. 62</u>

As the field contains 80 acres, the unit cost is \$14.02 per acre.

Results.

The work was completed in the spring of 1907. A great deal of water was discharged, apparently from every part of the system. Damp spots were dried and the spread of alkali stopped. Irrigation water was readily removed and the land was ready for cultivating early in the spring. Fair crops were raised the first season on portions that had been poor for several years. Ten acres of the Ogden farm, planted to oats in 1908, gave an average yield of 50 bushels, which is pretty good for that locality. Mr. Gardner has subjected his ground to a thorough leaching process and will cultivate a part of it this season (1909) with confidence of general success. Water

is still being discharged, and conditions are so gratifying that other projects are under way in this locality. A drainage district comprising 1,000 acres has been formed at Venice, where the farmers have great faith in the value of drainage.

WASHINGTON COUNTY EXPERIMENT.

This experiment is being made in the Washington field, near St. George, in the extreme southwestern part of the State. St. George was settled in the early history of Utah, and irrigation has been carried on for many years. The high-line canal, which waters all the land on the south side of the river and heads some distance up the Rio Virgin, was constructed in 1891-92. The land, with water rights, cost \$67.50 per acre, and when in good condition gives an annual return of \$20 to \$22 per acre for ordinary crops, and more for fruit or vegetable crops, which of course require more attention.

Subsequent to the opening of this field came a cycle of dry seasons. The land was irrigated copiously, and all portions bore abundantly. As the dry cycle kept up winter irrigation was resorted to, with a view of storing water in the soil. Heavy flooding was also carried on to prevent the usual settling of portions of the tract after planting. Another source of surplus water was that stored in ponds and used for stock-watering purposes. The natural result of all this was the accumulation of water in the low spots, the general saturation of the ground, and ultimately the appearance of alkali. The alkali spread rapidly until it covered more than 50 per cent of the cultivated area and caused its abandonment. The special reports cover the Washington field only, but the conditions in this field are typical of those in others.

A soil survey was made in 1905 by A. T. Strahorn, of the Bureau of Soils. The soil was classified into four types, Nos. 1, 2, 3, and 4.

Soil No. 1 is found in the extreme northwestern part of the field, well up toward the canal, and covers but a small area. It is a yellowish red sand, medium to coarse, containing small rounded gravel at various depths, and extends to a depth of 3 feet. Along the lower edge a fine silt has been deposited by irrigation waters. The soil is loose and on an elevation; so the drainage is good, and little alkali has made its appearance. After an application of water the surface bakes slightly, but crumbles easily. The soil was weathered from the hills on the west, the lighter portions being carried farther away. Alfalfa occupies the tract and yields from 4 to 5 tons per year in four crops.

Soil No. 2 covers most of the slope of the field, and is a red, sandy loam of uniform texture, having a depth of 3 feet or more. The only

variations are a layer of gypsum and sand hardpan in the southern part of the field, and a thin stratum of coarse sand. The nature of this soil is such that it is easily cultivated, bakes slightly upon being wetted, but offers no particular resistance to the growth of plants. It is not much affected by alkali and yields good crops of alfalfa, often 6 tons per season. Berries and fruits can also be grown to good advantage.

Soil No. 3 covers the floor of the lowland and consists of from 0 to 12 inches of loam or clay loam, brown or red, underlain by a red loam to 36 inches. The loam of the last foot is often replaced by a heavy sand loam. This soil comprises the "old lake bottom" and is heavy and sticky and difficult to handle, as it turns up in large clods, hard to pulverize, if plowed too wet. If plowed too dry, it powders and then puddles upon being irrigated. This puddled surface proves a barrier to the growth of grain. The soil was deposited from slow-moving or standing water, after the coarser grains had been left on the slopes. It is now so highly impregnated with alkali as to be unfit for cultivation, and is also a basin for all surplus water. A heavy growth of sedges and tules, with a border of salt grass, occupies the wettest parts. Useful vegetation has almost entirely disappeared.

Soil No. 4 covers a narrow strip on the west slope next the slough and consists of 36 inches or more of a clay loam, brown with organic matter in the surface, and represents the finest and latest deposit of the water-borne particles. Alkali is strongly evident, but the water table is lower than in that of soil No. 3.

There are large quantities of sulphates, considerable quantities of chlorids, and small quantities of bicarbonates in all of the classes of soil described. The alkali is quite uniformly distributed throughout the first 3 feet, being slightly stronger in the surface.

EXPERIMENTAL TRACT.

The location of the tract is shown on the field map (fig. 16), and local conditions on the experimental tract map (fig. 17). The soil is mostly No. 2, except in the southwest corner, where soil No. 3 is in evidence. This entire tract has been under cultivation, and all of it yielded abundantly except the north 20 acres, which seemed lacking in fertility. The tract owned by Mr. McArthur soon showed the effect of the irrigation of the higher lands. The wet area increased, and alkali appeared in sufficient quantities to prevent the growth of crops. The other tracts were partly affected in the same way. The Brown and Woodbury fields produced alfalfa only in the higher portions.

Plans and Construction.

These fields were examined in 1904, and the 1905 work was begun under a cooperative agreement, the owners to furnish the labor, while the Office supplied the materials and superintendence. The system consisted of four parallel lines running diagonally across the slope, equidistant from each other and intended to act as intercepting drains. The upper one, placed at the upper edge of the saturated area, was the only one crossing the entire tract. The object of this was to determine how far the effect would reach down the slope.

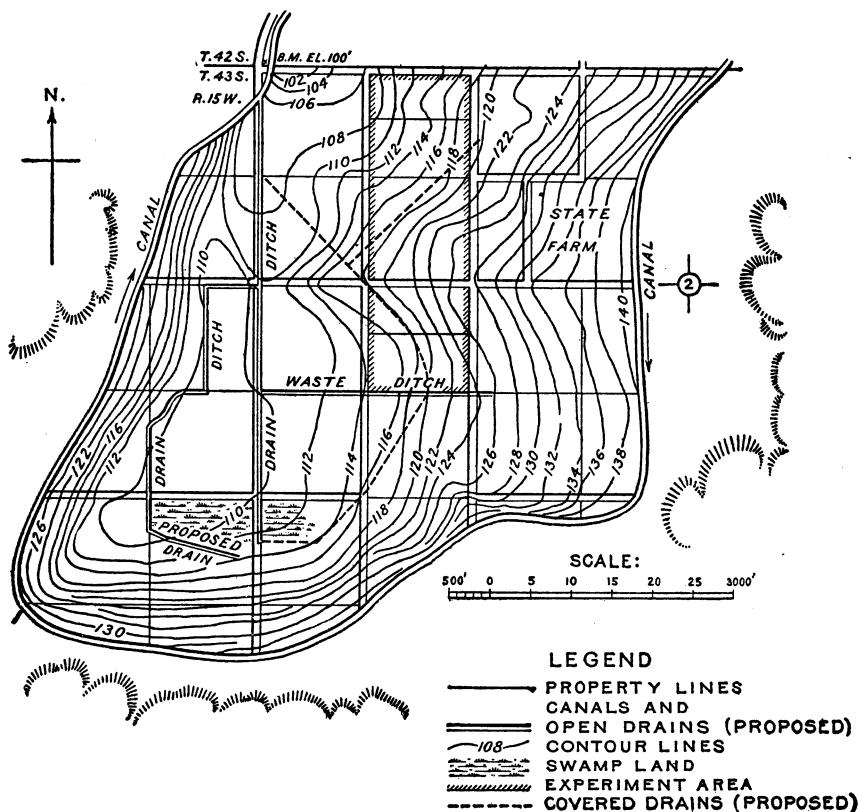


FIG. 16.—Map showing proposed drainage of Washington field and also location of experimental tract, St. George, Utah.

Lumber box drains were used, as the use of tile was prohibited by excessive cost. The lines were kept well away from trees to avoid the obstruction of the drains by roots. The depths were from 3 to 6 feet, and the grades from 0.1 per cent to 0.9 per cent. The tools used were long-handled shovels for digging and tile hoes for grading. The diggers worked in teams of two. Sections of the box drain were laid as the digging progressed. The drain was completed at a rate of 200 feet per day, at a cost of 95 cents per rod.

Cost.

The work of making boxes, digging, and laying was done together, so that separate costs could not be kept. The cost of making boxes

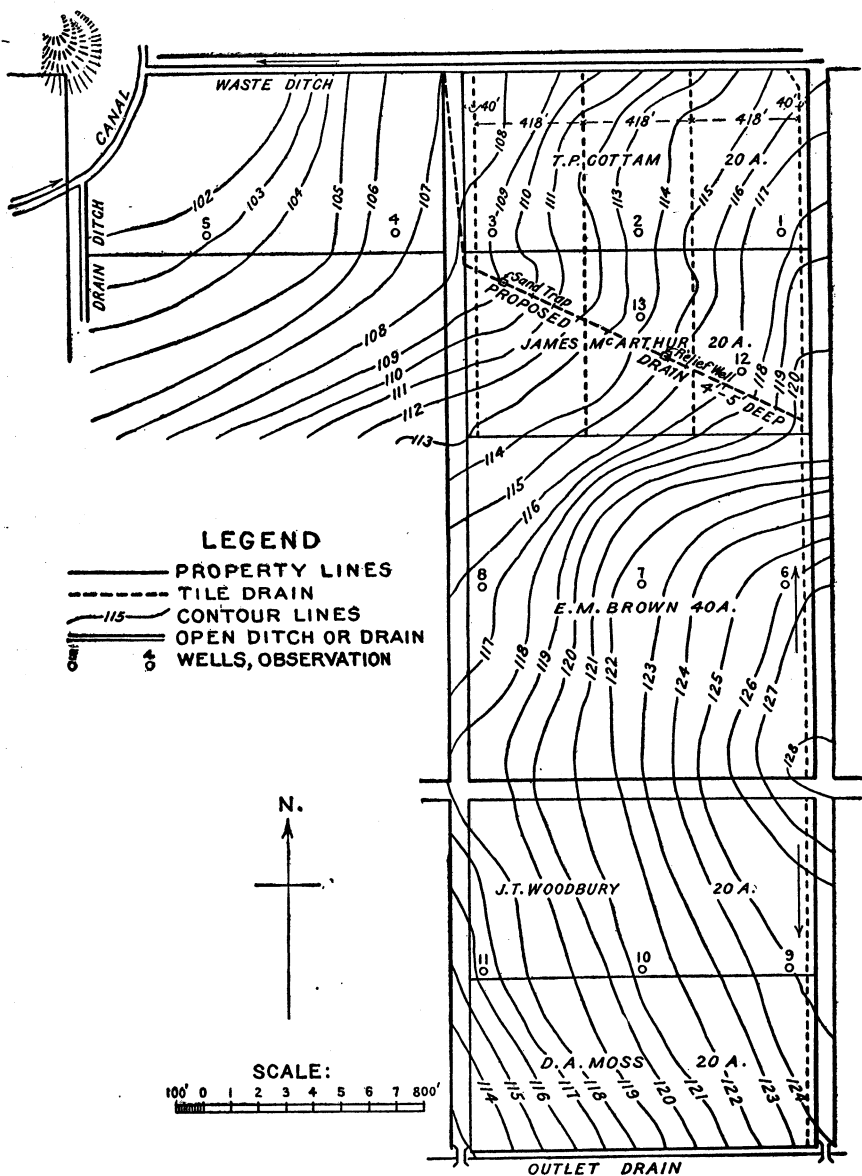


FIG. 17.—Plan of draining experimental tract, St. George, Utah.

would be about 70 cents per 100 feet. The following table shows the cost as done by different men. The Brown work was the heaviest. Mr. Moss used a team for a part of his work.

Cost of draining experimental tract, St. George, Utah.

Owner.	Acres.	Length of drain.	Cost per 100 feet.			Amount.	Total.
			Digging, making, and laying.	Filling.	Total per 100 feet.		
<i>Cost of labor.</i>							
T. T. Cottam.....	20	2, 672	\$3. 73	\$0. 60	\$4. 33	\$115. 70	\$401. 50
James McArthur.....	20	2, 672	4. 14	. 40	4. 54	121. 30	
E. M. Brown.....	40	1, 249	4. 40	. 72	5. 12	64. 00	
J. T. Woodbury.....	20	660	4. 39	. 83	5. 22	34. 50	
D. A. Moss.....	20	640	5. 78	1. 09	6. 87	44. 00	
Total.....		7, 893				379. 50	
Surveying.....						22. 00	
<i>Cost of material.</i>							
14,633 feet b. m. rough lumber, at \$31.50 per M.....						460. 94	
396 pounds 10-penny nails, at \$0.057 per pound.....						22. 57	
Grand total.....							
Actual cost per 100 feet for labor.....						4. 81	
Actual cost per 100 feet for materials and surveying.....						6. 40	
Total.....						11. 21	

Costs per acre range from \$3.60, where one line was used, to \$14.61, where four lines of drains were necessary.

Results.

The results of this system have not been very gratifying, although the ground-water level was lowered considerably, and, under the ordinary methods of cultivation and management, the crops showed an improved condition. Irrigation water found its way into the drains and carried a great deal of ground with it, with the result that the entire system has become inactive.

Extensions.

Some new work, using boxes with narrow openings and gravel-filter packed around the boxes, as at Huntington, was begun in 1908. This drain was installed on the farm of Mr. McArthur and consisted of a covered box drain running diagonally across the field from the southeast to the northwest at a uniform depth of 5 feet. A well, intended to relieve substratum pressure, was sunk near the center of the field and in line with the drain. This well was 10 feet deep and 4½ feet square and boxed up. Water rose in the well and flowed out of the drain, but as this movement was discontinued as soon as the ground-water level fell below the level of the drain, it is not thought to have been due to substratum pressure. The drain has a grade of 0.2 per cent for the first 100 feet to a sand trap, 0.8 per cent for the next 500 feet, and 1 per cent for the remainder of the length.

It consists of boxes 6 inches by 6 inches, having the bottom separated from the sides by means of short lengths of lath. The drain empties into a tight box conduit, 650 feet long, running north to the open ditch, along the county road, into which it discharges. This conduit is the property of the Washington Field Irrigation Company.

The trench was dug by hand, and back filled by means of a plow and two teams.

Cost.

Well and sand trap:

Digging well and casing same, 3 men 3 days, at \$2 per day	\$18. 00
Making casing, 1 man 2 days, at \$2 per day	4. 00
Lumber for casing	3. 00
Nails	1. 00
Rope for windlass	1. 75
Total cost of well	\$27. 75
Labor, making sand trap, 4 men 1 day, at \$2 per day	8. 00
Lumber	2. 00
Nails	. 75
Total cost of trap	10. 75
Total cost of well and trap	38. 50

Digging 86 rods of trench, making and laying boxes, and back filling:

Labor	163. 40
Nails	\$7. 20
Gravel	27. 52
Lumber	100. 05
Cost of material	134. 77
Total cost of trench	298. 17

To get an idea of the cost of draining land in this locality, data were taken from the previous experiment. Material is necessarily expensive by reason of the geographical position of St. George. The work was done in summer and also when the water was high, two important factors in increasing the cost of labor.

The total cost was shown to be \$298.17, which gives a unit cost of \$3.47 per rod and \$14.90 per acre. This cost will be increased slightly if it is found necessary to add a lateral to the system.

Results.—This drain was finished early in July, 1908, and discharged some water for a short period, but the water level soon fell below that of the drain, where it remained until November. During the winter a stream of about 0.05 cubic foot per second was discharged, more than half of which came from above the relief well. No prediction as to the ultimate success of this drain can be made at this time.

Proposed Extensions.

Some special examinations were made in this locality in the fall of 1908 to determine the source of the seepage which is destroying the lower Washington field. The theory had been advanced that the water was under pressure in the lower parts of the field, being confined by a hardpan, through which it found its way in weak places or breaks. If such conditions were found, relief wells were to be installed in the hope of providing an outlet for the water.

The examinations, carefully conducted, failed however to reveal any of the expected conditions, and wells placed in the most likely places gave no results. No hardpan layers were found at ordinary depths, nor

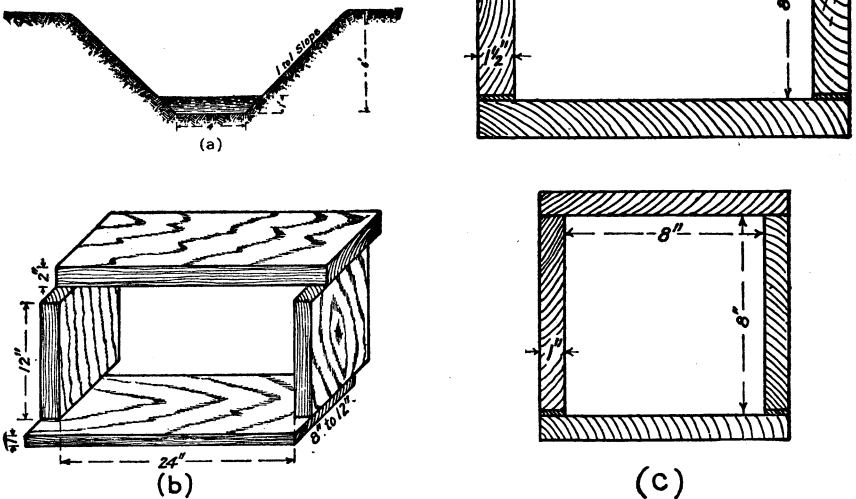


FIG. 18.—Proposed trench and drains for Washington field, St. George, Utah: (a) Cross-section of open trench for main drain; (b) detail of box drain for covered main drain; (c) cross-sections of box drains for branches I, II, and III.

was any water under pressure discovered. The ground water was fairly level throughout the slough and continued level until it pinched out on the slope, on the west and south sides, and the south-east corner. On the east side, throughout the length of the experimental tract, however, the water followed the slope of the surface up to within one-quarter mile of the canal, whence it again became

nearly level. It was also found that the ground under the canal was as dry as dust to a depth of 15 feet. These facts seem to indicate that the water comes directly from irrigation of the higher lands in the field. The investigations, in connection with past experience and data gathered at various other times, point out the necessity of constructing deep, open ditches of ample capacity, tapping the lowest portions of the field and discharging toward the river. As an important supplement, carefully placed intercepting drains should also be used on the gentle slope to the east. The branch drains should be covered and the main also, where it cuts through boggy places; or, as the main would lie along a public highway, it might be advisable to have the whole length covered. A proposed system is shown on the map (fig. 16, p. 37). Sections of the proposed trench and conduits are shown in figure 18, *a*, *b*, and *c*.

Estimated cost,

Excavating main drain, 12,845 cubic yards, at 15 cents per yard.....	\$1, 926. 75
Excavating trenches for branches, 14,250 feet, at 7 cents per foot.....	997. 50
Lumber for small boxes, 25,000 feet b. m., at \$30 per 1,000 feet.....	750. 00
Lath, 36 bundles, at 25 cents per bundle.....	9. 00
Nails, 505 pounds 10-penny and lath nails, at 6 cents per pound.....	30. 30
Lumber for branch II, 30,187 feet b. m., at \$30 per 1,000 feet.....	905. 61
Gravel for filling around boxes, 14,250 feet, at 2 cents per foot.....	285. 00
Labor in making and laying boxes, 14,250 feet, at 1 cent per foot.....	142. 50
Back filling, 14,250 feet, at 1 cent per foot.....	142. 50
Total.....	5, 189. 16

If it is found advisable to use a covered main, the following will be the cost of same:

Excavating trench, 5,780 feet, at 14 cents per foot.....	\$809. 20
Lumber, part A, 17,600 feet b. m., at \$30 per 1,000 feet.....	528. 00
Lumber, part B, 15,840 feet b. m., at \$30 per 1,000 feet.....	475. 20
Lumber, parts C and D, 35,586 feet b. m., at \$30 per 1,000 feet.....	1, 067. 58
Labor, making and laying, 5,780 feet, at 3 cents per foot.....	173. 40
Nails, 1,126 pounds 10-penny and lath nails, at 6 cents per pound.....	67. 56
Back filling, 5,780 feet, at 2 cents per foot.....	115. 60
Total for covered main.....	3, 236. 54
Cost of branches.....	3, 262. 43
Total, using covered main.....	6, 498. 97
Total, using open main.....	5, 189. 16
Difference	1, 309. 81

Cost per acre, using open main, \$6.83; using covered main, \$8.55.

This proposed system, as elaborated by experience in the field, is a development of the original plans.^a

^a U. S. Dept. Agr., Office of Experiment Stations Bul. 158, part 9.

DRAINS IN THE TOWN OF ST. GEORGE.

During the fall of 1905 the town council put in a lumber box drain, following the plan of the field work, under direction of the drainage

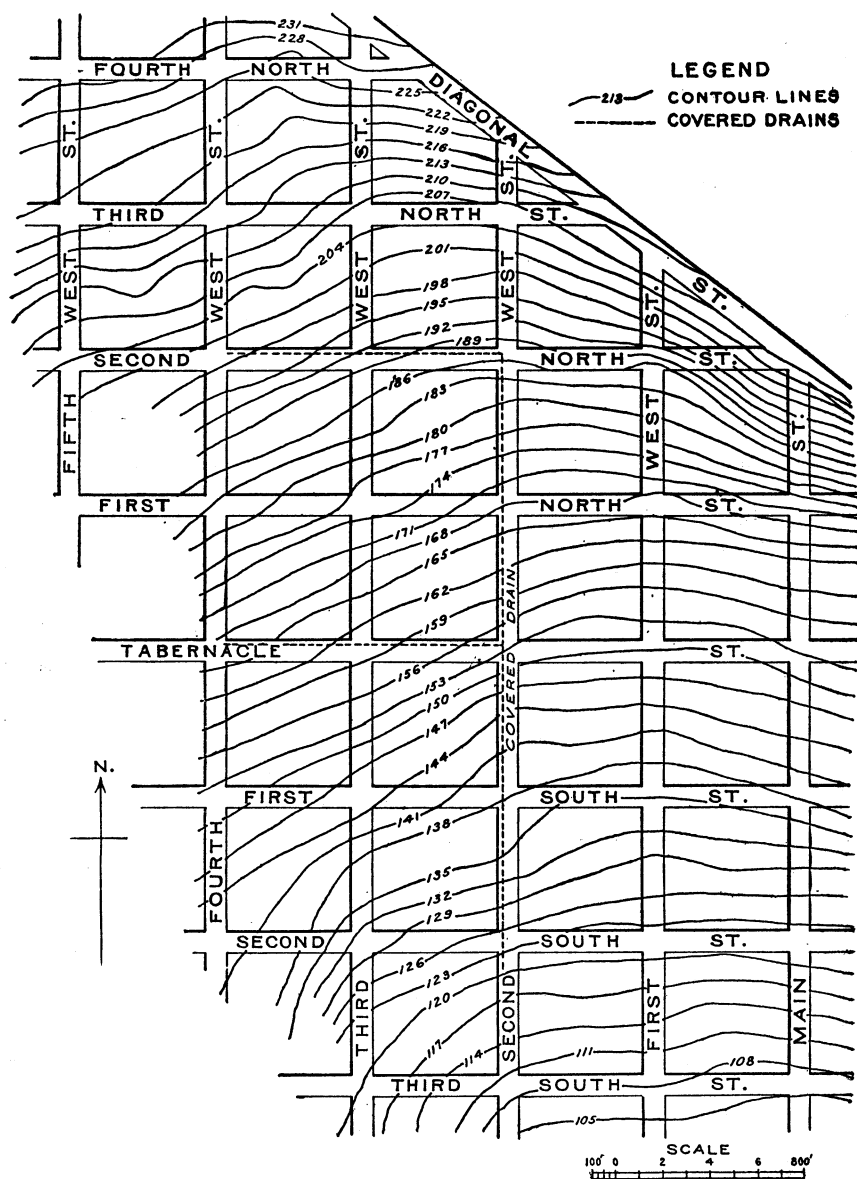


FIG. 19.—Town drainage map, St. George, Utah.

engineers of this Office. The main was laid up Second West street, as shown on the accompanying map (fig. 19), and two laterals west on

Tabernacle and Second North street to Fourth West street. This portion of the town had been wet for several years and was typical of the field condition. The drains were made of 1-inch by 6-inch boards, without bottoms, and were laid on an average of 5 feet deep. Grades ranged from 1 per cent to $2\frac{3}{4}$ per cent. Some construction troubles were encountered. Quicksand and loose ground gave some trouble, and several ridges of cemented sand, running east and west, made the use of a pick necessary.

This system has proved very successful, and extensions are planned. Wet places were dried and vegetation greatly helped. Some care here has also been found necessary to prevent irrigation water from finding its way into the drains. Such trees as the tamarack can not be permitted in the vicinity of the drains. During the last year trouble has been occasioned by the water cutting outside of the boxes and letting the surface ground fall in, thus leaving objectionable holes. Hereafter the city will use drain boxes with bottoms and with gravel packed along the sides.

DRAINAGE OF IRRIGATED LANDS IN OTHER STATES.

Passing to other States, it should be noted that irrigated land has been successfully drained by some one of the methods employed in Utah. Some of the wet lands about North Yakima, Wash., have been reclaimed by underdrains placed diagonally across the slope at a depth of 5 feet, in such a manner as to intercept the underflow from the higher lands, which are so largely underlain by gravel as to permit a ready flow of soil water to lower lands. These drains are discharged into receiving drains, either open or covered, which lead the water to some natural stream. Where the construction of the intercepting ditches has been omitted the land has not been satisfactorily drained.

The well system has proved valuable and often efficient in sections of Colorado, where the gravel which supplies the water lies 8 or 9 feet below the surface, and also in some instances where the loose loam soil rests upon a stratum of hard clay. Wells of any convenient cross section are excavated to the water-bearing stratum, from which a tile or box conduit, laid about 4 feet deep, leads the water which rises in the well into a receiving drain.

Where the land is level and the soil fine and homogeneous in character, like that near Fresno, Cal., it has been found best to lay underdrains about 6 feet deep directly through such lands as are affected by seepage and alkali. These collect soil water from a considerable distance on either side by ordinary percolation and deliver it into a sump, from which it is pumped into surface ditches. The difficulties which attended the construction of the drains in the Fresno dis-

trict were similar to those described elsewhere in this bulletin. It has been found necessary to observe the same precautions in the subsequent management of both drains and fields as is found necessary in Utah.

PRINCIPLES AND PRACTICE.

LANDS NEEDING DRAINAGE.

Irrigated lands needing drainage may be divided into three classes:

- (1) Those injured by excess of water only.
- (2) Those affected by an excess of both water and alkali.
- (3) Those having an excess of alkali only.

The first class is the least extensive of the three, the extent of injury depending upon the value of the crops that may be grown on the land when dry. The greatest danger of serious loss in this kind of land is that alkali may accumulate in injurious quantities with the lapse of time. In the irrigated region there is very little seepage water which does not contain some alkali in solution, which tends to accumulate to an injurious degree in saturated land. Inquiry into the history of lands which have become badly affected with both alkali and water show that when injury first became noticeable such lands could have been protected from further injury with as much profit as attended the reclamation of lands affected by water only.

It is to the second class that most of the lands belong which now need drainage in the irrigated sections. Alkali accumulations usually follow accumulations of seepage water. If one admits that this condition is a forerunner of total abandonment, surely no argument is necessary to convince him that such lands belong to the class that should be drained.

Lands of the third class are principally those in the virgin state, having enough alkali uniformly distributed through the soil to a depth of 6 feet to cause crop failure after a few years of irrigation, because of insufficient underdrainage. The lowlands of Millard and some of those in Salt Lake, Weber, Boxelder, and Emery counties, Utah, belong in this class. If irrigated lightly, the alkali will in time become concentrated at the surface, and if irrigated copiously, without underdrainage, water-logging will follow.

ALKALI AND GROUND WATER.

The relation of alkali to drainage is important and must be taken into account. In speaking of alkalies in his book on "Soils," Hilgard says:

They are the natural result of a light rainfall, insufficient to leach out of the land the salts that always form in it by progressive weathering of the rock powder, of which all soils largely consist.

Ordinarily alkali is made up of one or more of the following salts in varying proportions: Sodium chlorid (common salt), sodium sulphate (Glauber's salt), magnesium sulphate (Epsom's salt), calcium chlorid, and calcium sulphate, all of which are white alkalis, and sodium carbonate (sal-soda) or black alkali. The latter is so called on account of the dark stains on the ground caused by the dissolution of the soil humus or vegetable matter. These salts and also the mineral plant foods are readily soluble in water, so that in the humid countries the constant leaching removes not only the injurious salts but also part of the plant foods. This accounts for the intrinsic fertility of the arid lands as compared with humid lands. The account of the origin of alkali naturally suggests the control by irrigation and underdrainage.

Of the fundamental principles, those relating to ground water and its movements are perhaps the most important. There is no question that seepage is an actual accompaniment of all irrigation. It has been found in all irrigated countries, doing damage and requiring drainage. The sources of supply are leakage from canals, surface applications, and precipitation. If the soil has the capacity for discharging this water as fast as it is supplied no damage will be done. If, on the other hand, more than its capacity is supplied trouble will surely follow. Soils in the Bear River Valley, Utah, having a depth of 40 feet and a fair surface slope have been known to fill after fifteen years of irrigation until water rose to the surface, doing considerable damage.

A proper appreciation of seepage conditions often involves a knowledge of the ability of water to transmit pressure between two points, due to differences of elevation. This is often manifested in irrigated sections by ground water springing up through the innumerable soil pores. Such a condition indicates a porous substratum filled with water exerting a pressure. When this substratum is too deep to cut into by a drain, outlet wells connecting with the drains at an ordinary depth afford the best solution.

Another physical property affecting the movement of ground water and of great importance is that called capillary attraction. This phenomenon was named from the inherent ability of liquids to rise in small hair-like or capillary tubes above their free surfaces. Water rises higher in the tubes and also in soil particles than any of the other liquids. This property is most essential to plant life and crop production, but uncontrolled in alkaline soils it hastens the accumulations of alkali at the surface. In soils varying from coarse sand to very fine clay, water will rise by this attraction from 2 to 6 feet. When the surface is allowed to become hard and baked, as when abandoned or allowed to stand idle, a surface tension is formed which

increases this attraction and the consequent evaporation. It is the evaporation of large quantities of water containing alkaline salts in solution that does the damage. The evaporated water passes off nearly free, leaving the alkali in the surface soil. Experiments have shown that of the water applied in ordinary irrigation, without cultivation, from 30 to 50 per cent is evaporated from the surface. If, in addition to this, seepage water from higher lands or canals containing much alkali is within reach of capillary attraction, and the surface poorly cared for, thus increasing evaporation, alkali accumulations surely follow. A minimum depth of 4 feet for drains, with cultivated or shade crops, has been the practice of the drainage engineers of this Office, though deep drainage from 5 to 6 feet is preferred.

PLANS FOR DRAINAGE.

The soils of the arid regions have not been subject to percolating water since their formation, as the humid soils have been, and consequently are without the drainage pores of the latter. If they have any water pores at all, they are those of the water doing the damage. The water applied to the higher lands affects the lower lands, where it flows out or comes near the surface, whether in light or heavy soil. In moving laterally through the body of the soil the water will flow along the lines of greatest slope and will not drain well into tile lines parallel to its movement. The drainage water in all of these experiments has found its way through some special underground passage, or stratum, or some modification of these, rather than uniformly through the soil. The experiments in Emery and Weber counties were particular examples of the flow through some special underground passages, while the others were modifications. Conditions similar to those in Emery and Weber counties were observed in Paonia and Delta, Colo. At both of these places the efforts to drain the land were proving unsuccessful. These and a dozen other illustrative examples may be cited where special treatment was necessary; but those named are enough to show that the method of intercepting the water as it enters the field or soil, either by lateral seepage or some lower passage, is highly essential to success. However, intercepting drains are not all that are necessary. In nearly every instance outlet lines through the lowest wet portions are absolutely necessary, as is the case in humid sections.

Before drainage work can be taken up with any surety of success these underground conditions must be determined. If expensive mistakes are to be avoided, the subsoil examinations must not be neglected. The first method of making such examinations is that of digging test pits. Under ordinary conditions a depth of 6 feet can be reached without any difficulty. The test pit is also valuable for

showing the nature of the digging for which special methods may be necessary. Another method is to use a soil auger, made of a 2-inch wood bit and $\frac{1}{2}$ -inch gas pipe, with which holes can be put down 12 feet, if gravel is not present. A long steel rod probe $\frac{5}{8}$ inch in diameter can often be used to advantage in soft ground.

The kind of drain to be employed in farm drainage will be determined largely by local conditions. Open ditches are sometimes used for farm drainage, but more often for outlet and main drains. The principal objections to the use of open ditches for farm ditches are the loss of land and the high initial cost if sufficient side slope is given them. If side slopes are left steep the maintenance expenses are high.

Covered drains may be divided into the following forms: Tile, lumber boxes, stone, brush, and mole-plow drains. Burned clay tiles, chiefly in a round form and in 1-foot sections, have been in use for more than four hundred years and have proved satisfactory. They have been known to endure for one hundred years. Some kinds of clay tile, when left upon the surface of the ground, will be disintegrated by soil alkali and by freezing. The old idea that tile should be porous has been abandoned.

The use of lumber box drains has been described in the preceding pages in connection with the experiments in Emery and Washington counties. Stone box drains have not been used to any extent in these districts so far as known, but brush and loose rock drains have been observed to fail by filling with sand and silt.

If farm drains must be laid along lines of water-loving trees and within 100 feet of them, the drains should be open ditches to prevent roots from obstructing them. The need of covered drains in orchards requiring drainage has necessitated a method of removing the roots without removing the tile. In California, cables are strung through the tile and root brushes pulled through short sections. A similar method was also employed in the Point Lookout experiment, as previously mentioned.

The questions of locating the lines and determining their sizes and depths will have to be determined by judgment, applying the fundamental principles herein stated. No general directions, such as a gridiron, double main, and single line or parallel systems, commonly used for drainage in humid districts, can be given for this kind of drainage. Such systems, with parallel lines 1 rod apart, might fail entirely if applied to some irrigated fields. If after careful examination the trouble is located as lateral seepage, a single line should be laid across the line of greatest slope 2 to 6 rods below the upper line of the wet spot. Such spots are usually small and one line may be sufficient, but an outlet line or branch should be laid through the low

ground or basin. The distance down the slope affected by a drain will vary from 300 to 2,000 feet, according to local conditions. If the source is found to be in particular spots, as at Huntington, Emery County, a branch for each spot will be necessary. Wells as outlets for water-bearing porous substrata should be located at the end of the pocket if it pinches out, and on the lowest ground if it extends all the way under the tract.

Lateral and main outlet drains should be clear to a depth of 5 feet, especially if they are intended for farm outlets on such land. The depth of covered drains for arid soils is determined by two factors. The first is the depth of the drained soil necessary for different crops. For grasses and cereals a soil depth of 3 feet is sufficient. Fruit trees and alfalfa should have from 5 to 6 feet, and still greater depths are advantageous. The other factor in alkaline lands is capillary attraction. The height to which water will rise and evaporate in large quantities is the minimum depth allowable for ground-water level. Generally the water should be kept from 4 to 6 feet below the surface to satisfy these requirements. The minimum grade is 0.1 per cent and may be increased to as much as 5 per cent if necessary. Sizes from 4 to 6 inches will be sufficient for laterals in clay soils, with larger sizes for coarser soils. A study of the plans given in this bulletin will show that fewer drains are needed in the irrigated sections than in the humid.

Plans for drainage other than small inexpensive lines should always include surveys. Level surveys, both preliminary and final, are absolutely necessary. The need of surveys for expensive tile or open ditch work ought not to be questioned. The enormous losses to farmers and cooperative companies in the past, when constructing irrigating works without competent engineering supervision, should be a lesson, and similar mistakes should not be repeated in undertaking expensive drainage works. At the time when final surveys are made the lines should be tied up to or located with reference to permanent marks, and a map of the system made. Such a map may prove valuable in planning future extensions and in other ways, when otherwise the exact location would be forgotten.

FIELD CONSTRUCTION.

The tools most used for digging trenches are trenching spades, shovels, and tile scoops. Tile trenching machines are being introduced, but the chief dependence for this work will be hand labor. The digging for farm drains should always begin at the outlet, finishing the work as it proceeds, except completing the back filling. For trenches not deeper than 5 feet and for sizes of tile up to 12-inch, the

top width need not be more than 18 inches. To insure proper alignment one side should be lined for the first spading. The last 16 inches should be removed in the last spading and the bottom graded at the same time. The work is much more easily done this way than if the digger were lower in the trench, and the bottom will remain firmer if not mushed up by constant tramping. Very few trenches can be finished in the irrigated districts without the trouble caused by the banks caving in, so that it is necessary to keep the tile laid and the trenches partly back filled up to within a few feet of the finished trench, and for that reason two or three diggers with one tile layer make the best team. With proper care the grade should only vary within one-fourth inch of true grade.

Laying tile is an important part of the proper construction of drains, even when the trench is made straight and on a uniform grade. The first item of importance is providing a firm foundation on which to lay the tile. In irrigated lands there are often soft spots which need some special treatment. The best method in such cases is to lay long boards in the trench upon which to lay the tile. If some such precaution is not taken one or more tile may settle or be pressed out of alignment and form a complete obstruction. When laying tile through an orchard with the intention of operating a brush or root cutter, boards with cleats on each side to hold the tile in true alignment are sometimes used. Tiles are not always cut off squarely, and when laid they should be turned until the tops set closely together, leaving the bottoms open for water. The ground should be firm enough to hold a man on a blinded tile, and the tile layer should work from the tile, if need be. Tile should always be carefully covered or blinded, as it is called, as soon as it is laid; and, for safety, the trench should be back filled enough to prevent the banks from caving in. Sand-trap boxes, as described in the experiment at Garland, Boxelder County, should always be put in at intervals of 300 to 500 feet, when fine sand or silt troubles occur, and also in orchards. These may be used as inlets for water when flushing tile or boxes.

After the tiles have been blinded and the trench partly filled by hand, the balance of the filling may be done with horses and plow. Three horses and a long evener are used for the first plowing. This plowing should be from the edges of the trench, after which a team may be used, one horse walking in the trench. It is not necessary to fill loosely so that the water may get into the tiles. Tramping and tamping are necessary to prevent surface water from entering and doing much damage. For the same reason, all brush and weeds should be removed, and not used for filling. The plowing should be continued until a heavy back furrow is worked up over the line.

SUBSEQUENT CARE NECESSARY.

Attention to drainage should not cease when the system is installed. Upon the subsequent care and treatment of the drains and drained fields will depend the final efficiency. One of the greatest sources of trouble, in covered drains especially, has been the damage resulting from surface water running into the trench. In some soils it has been necessary to place boxes or flumes for carrying irrigation water over trench lines to keep the water from finding its way down through the loose soil to the drain with resultant obstructions. These troubles occur in sandy and silt loams but not in clay loams. Tree and brush roots cause much trouble by growing into covered drains in search of water, and then developing enough water roots to seriously interfere with the flow of water. Alfalfa roots will also cause obstructions in tile after several years, and the report of the Hyde Park experiment (Cache County) contains an account of serious troubles caused by beet roots. To prevent excessive evaporation the proper cultivation of the surface is necessary. As explained before, a hard, smooth surface increases the evaporation of soil moisture. Where possible such soils should be cultivated after each irrigation so as to form a mulch on the surface. Shade crops, such as alfalfa, are also useful in preventing evaporation. Cropping and copious irrigation are absolutely necessary for reclaiming alkali lands after underdrainage is supplied.

SUMMARY.

(1) The extent and value of lands in the arid West needing drainage make this a question of great importance. Most of these lands once produced abundant crops, but now they lie idle or produce only a small portion of what they should. Nearly every agricultural district in Utah, Washington, Montana, Wyoming, Colorado, and California has large areas in this condition.

(2) The value of understanding the fundamental principles of drainage, in preventing the increase of such conditions and reclaiming those lands now affected, can hardly be overestimated. Millions of dollars would have been saved in the West if the injurious results of seepage water and alkali and the methods of preventing them had been known and appreciated. Some knowledge of the nature and source of alkali, together with its relation to crop production, is essential. The reports of experiments in Utah, Washington, California, and Colorado, contained in this bulletin, afford proof that such injuries could have been prevented at a reasonable cost.

(3) Success is dependent upon correct plans and proper construction of drains. Careful and systematic surveys and subsoil examinations should never be omitted. The form of drain or section of

ditch should be chosen with reference to its efficiency in the particular soil formation and water conditions.

(4) The subsequent care and treatment of drains and lands will also determine the ultimate success. In humid countries drainage systems, once well laid, take care of themselves and usually operate successfully for many years. Drainage systems in arid countries, where irrigation is practiced, require watching and treatment after they are laid. The care is necessary in relation to surface waters, and the treatment of lands necessary when they are affected with alkali.

(5) The cost of draining the lands described in these investigations is the basis for the statement that such lands can be profitably drained. The Hyde Park lands, formerly only fit for pasturage, were drained at a cost of \$15.60 per acre. During the two following years different portions were planted to oats, wheat, and sugar beets. The yields were 100 bushels of oats, 50 bushels of wheat, and 18 tons of sugar beets per acre. The Garland wet land was drained at a cost of \$16.87 per acre, which raised the land value from less than \$100 to \$150 per acre.

The Getz farm at Point Lookout, which was badly alkalied and produced practically nothing, was drained, producing 35 bushels of oats per acre the following season. The Hobson farm at Roy, Utah, was drained at a cost of \$13.67 per acre, which enhanced its value \$25 per acre. The Richfield tract is well drained at a cost of \$14.02 per acre, and the land, formerly worth \$25 per acre, promises to reach the \$100 mark. Lands in Weber and Davis counties, valued at \$150 to \$300 per acre, have been preserved by draining at about the same cost as those above mentioned. The Huntington and St. George tracts are not yet reclaimed, but it is expected that the cost of reclaiming such lands, according to methods now in use, will fall within or close to the highest costs given here.